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VOLUME XIX July, 1949 *NUMBER 7*

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AND

THE TEXTILE FOUNDATION

Editorial Office: 10 East 40th Street, New York 16, N. Y.

Rayon Reports

Prepared Monthly by American Viscose Corporation, New York, N.Y. JULY, 194

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VOL. XIX, NO. 7 July, 1949

In This Issue

The Effect of Variations in Degree of Structural Order on Some Physical Properties of Cellulose and Cellulose Acetate Yarns
Robert W. Work 381

An Improved Multipurpose Abrasion Tester and Its Application for the Evaluation of the Wear Resistance of Textiles
R. G. Stoll 394

A New Method of Evaluation of the Crystallite Orientation of Cellulose Fibers from X-Ray Data—Appendix
P. C. Tsien 416

INDUSTRIAL SECTION

A Study of the Bleaching of Blue Cotton Fiber
R. E. Hudson, Jr., and Howard M. Waddle 421

Evaluation of Roll Wool Felts for Arctic Footwear
Thora M. Plitt Hardy 427

Some Recent Developments in Cotton Research at the Southern Regional Research Laboratory
Walter M. Scott 436

Abstracts 444

Editor: Julian S. Jacobs *Managing Editor:* Julia M. Crisp

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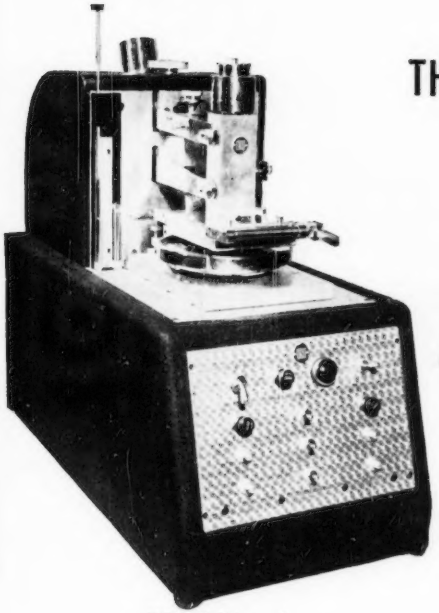

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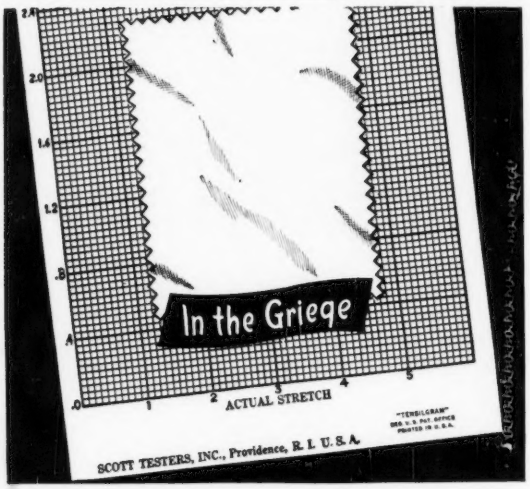

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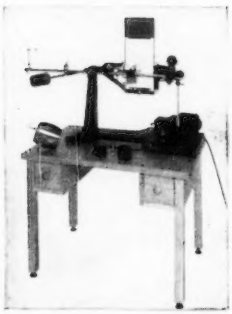

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VOL. XIX, No. 7 July, 1949

The Effect of Variations in Degree of Structural Order on Some Physical Properties of Cellulose and Cellulose Acetate Yarns*

Robert W. Work†

Celanese Corporation of America, Summit, New Jersey

Abstract

It is shown by means of x-ray diffraction diagrams that cotton, a highly crystalline and oriented material, gives a triacetate of low crystallinity which may be rendered more crystalline by annealing. This triacetate is partially hydrolyzed to form the secondary cellulose acetate used in textile yarns, which gives an x-ray pattern showing a highly amorphous structure. Although steric effects prevent increases in crystallinity by annealing, this type of yarn can be oriented, the degree of orientation depending upon the conditions under which stretching of the yarn takes place. By swelling and allowing limited mobility, this orientation may be increased over that produced by dry stretching. Cellulose acetate fibers may be converted into highly crystalline celluloses, the orientation of the original material carrying over into a hydrolyzed product. The load-elongation characteristics of families of these 2 types of yarns are described and the effects of orientation are discussed. The decrease in lateral strength, due to orientation, is illustrated by means of electron micrographs of the material. The relationship between orientation in series of cellulose acetate and corresponding cellulose yarns having greater or lesser degrees of orientation and the sonic moduli of these materials are illustrated. Possible explanations are suggested. Dye retention similarities between mature cotton and slightly oriented cellulose yarn on one hand and immature cotton and unoriented cellulose yarn on the other hand are given to indicate that orientation may be one basic difference between mature and immature cottons.

Introduction

Comparatively little has been published on the highly oriented cellulose acetate yarns and the cellulose yarns derived therefrom. For this reason, a general paper was prepared and presented at the Annual Meeting of the Textile Research Institute (Nov. 18, 1948), which reviewed selected physical properties of these yarns and indicated some of the more recent research on them. The data presented were chosen from the wide research studies made over a period of years by the staff of the Celanese Corporation of America and also included recent contributions of the Fabric Research Laboratories,

* This paper was presented at the Annual Meeting of Textile Research Institute, New York, on November 18, 1948.

† Head of Physical Research Department, Central Research Laboratories, Celanese Corp. of America, Summit, New Jersey.

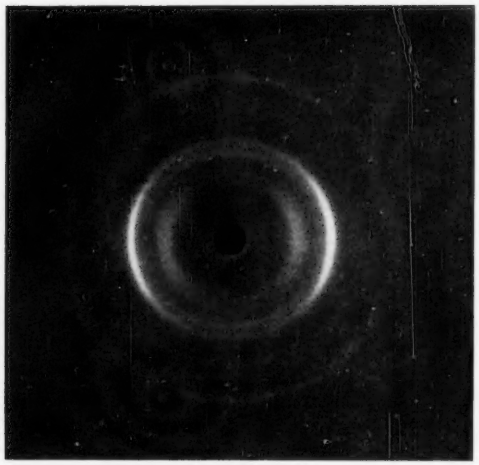

FIG. 1. *X-ray diffraction pattern of cotton fiber.*

Inc., the latter organization being consultants of the former. In view of the nature of the original oral presentation, its text has been followed with only such changes as have been made necessary by its conversion to the form required in publication.

Structural Order as Shown by X-Ray Diffraction Patterns

Raw Materials and Intermediates of Cellulose Acetate Yarn

Cotton is one of the raw materials used in the manufacture of cellulose acetate. Also, it is virtually pure cellulose and therefore chemically the same as the regenerated cellulose discussed in this paper. For these reasons, it is well to open the subject by reference to its x-ray diffraction diagram (Figure 1). In this well-known diagram it is seen that cotton cellulose is neither amorphous nor completely crystalline—rather, it contains some of each component. The parent film shows the presence of the former by general darkening due to scattering. The circles indicate the presence of crystallinity and its lack of perfection is shown by their width. But since some of these are not complete circles but rather are arcs, it may be concluded that the small and imperfect crystalline parts are somewhat oriented in relation to each other, to the fiber axis, and the x-ray beam. From a study of the positions and intensities of the arcs, much information may be learned of the arrangement of atoms in the cellulose molecules and in turn of the positions of these molecules relative to each other. However, suffice it say that cotton exhibits both crystallinity and orientation to a limited extent, since a comprehensive study of cotton does not fall within the scope of this paper.

The structural order of cellulose disappears during the normal process of esterification, it being easy to follow this change by means of x-ray diffraction examinations of the reacting solids. For example, the typical diagram of native cellulose becomes hazy as the acetyl groups from the acetic acid become chemically combined with the cellulose. As the triacetate is approached, as evidenced by the acetyl value of the material, a new diffraction diagram appears and ultimately replaces the cellulose diagram completely. There has been some confusion regarding this reaction and the x-ray patterns obtainable from the intermediate reaction products. However, such difficulties may be resolved by extracting the intermediate products with a solvent for cellulose triacetate in order to separate it from unreacted cellulose. It is then found that the insoluble residue gives a sharp native cellulose diagram and the soluble portion, after evaporation of the solvent, gives the typical cellulose triacetate diagram. Although this cellulose triacetate is not the material used commercially in the manufacture of textiles, for purposes of research it may be spun into

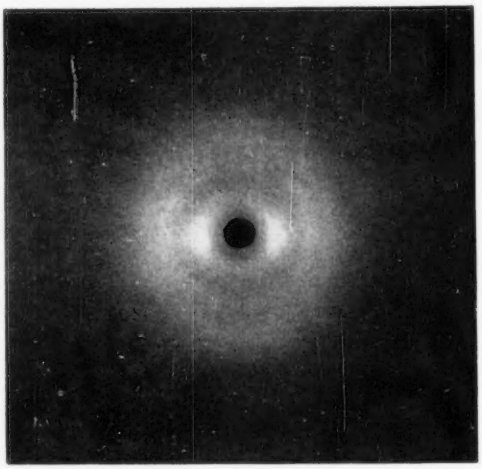

FIG. 2. *X-ray diffraction pattern of cellulose triacetate filament.*

filaments. The x-ray diffraction diagram of such a filament is shown in Figure 2. The rather indistinct arcs indicate that a certain amount of crystallinity is present, although the haziness shows that much amorphous material is also there. Exact measurements of the dimensions of these rings lead to the conclusion that the original cellulose unit cell has been modified somewhat. In addition, all of the hydroxyls of the anhydroglucose ring are acetylated and this uniformity along the chain molecules allows the molecular segments to associate with each other quite regularly. By raising the material to a temperature slightly below its melting point, these molecular segments are able to rearrange somewhat and thereby obtain a more regular or crystalline relationship. The result of such an annealing operation is illustrated in Figure 3. In this pattern the rings and arcs are sharper than before annealing, indicating that crystallinity has increased.

Cellulose Acetate Yarn

Although cellulose triacetate is not a textile material, it is always an intermediate in the manufacture of the commercial grade of cellulose acetate, commonly known as secondary cellulose acetate. This last is secured by hydrolyzing off of the anhydroglucose ring some of the acetyl groups so that the average number of acetyls per anhydroglucose ring is less than 3 but more than 2, with the remaining groups (equal in number to the difference between the number of acetyls and 3) being hydroxyl groups, as in the original cellulose. Such cellulose acetate in the form of a textile fiber gives the x-ray diffraction pattern shown in Figure 4. A very great change in structural order has taken place as the result of the chemical changes occurring in partial hydrolysis. The crystallinity has decreased so that only two very broad circles are produced. The trace of lightening at the sides of the circles indicates that the crystalline areas are further, slightly oriented, relative to the lengthwise direction of the yarn. This orientation is very small indeed, and it can be predicted that the physical properties which depend upon structural order will be practically equal in all directions. Furthermore, it is impossible to produce an appreciably increased amount of short-order regularity by an annealing operation, such as is the case with cellulose triacetate. This is due to heterogeneity in the molecular segments along the chain molecules. As a result of this heterogeneity the acetyl groups and the hydroxyl groups are unable to pack together with any great amount of regularity when a small degree of mobility is supplied to them by raising the temperature. This is an example of steric disorder due to heterogeneous side groups—the acetyls and the hydroxyls—being randomly placed along the chain molecule.

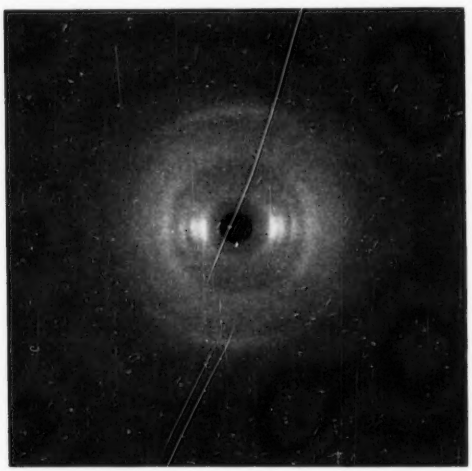

FIG. 3. *X-ray diffraction pattern of cellulose triacetate filament after annealing.*

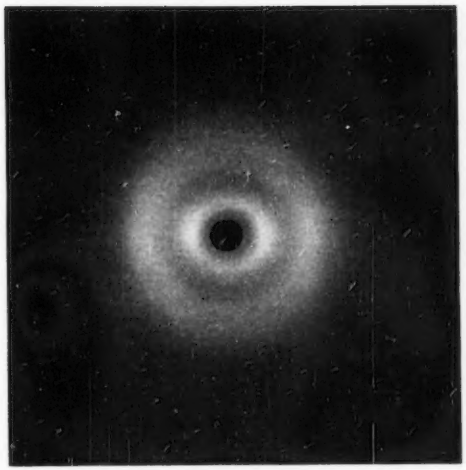

FIG. 4. *X-ray pattern of cellulose acetate filament.*

However, changes tending to bring one kind of order from this disordered state may be effected by

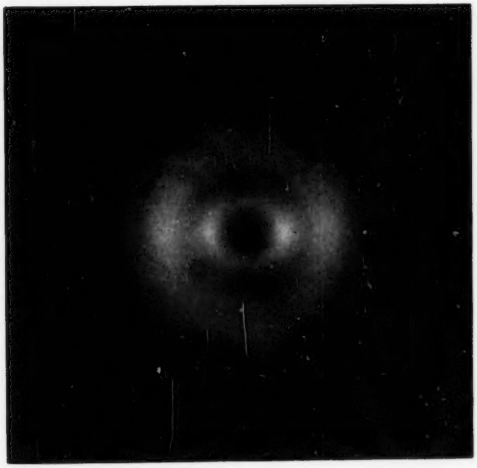

FIG. 5. *X-ray diffraction pattern of cellulose acetate yarn dry-stretched to slightly less than its breaking elongation.*

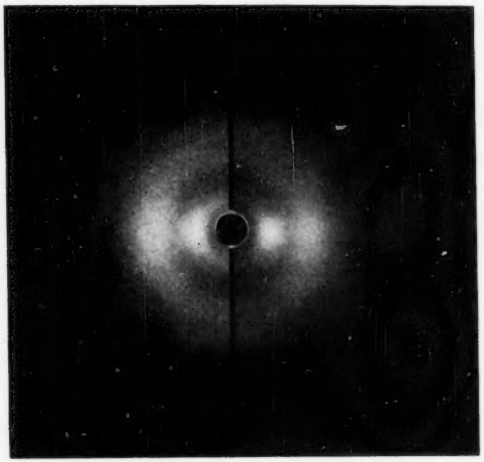

FIG. 6. Left—*X-ray diffraction pattern of cellulose acetate yarn dry-stretched to slightly less than its breaking elongation.* Right—*X-ray diffraction pattern of cellulose acetate yarn stretched when swollen.*

proper treatment of cellulose acetate. By stretching the yarn—as, for example, in a serigraph—to just short of its breaking point, a change is produced, the x-ray diffraction pattern of which is illustrated in Figure 5. In this diagram the inner complete circles of the original material have become somewhat more light at the left and right sides. The same is true of the outer ring. Yet the diagram taken as a whole is still as fuzzy as that of the unstretched yarn. This indicates that some orientation of the small crystalline areas has taken place but it is doubtful whether the crystalline areas have grown in size or become more regular. With the advent of orientation of this degree, corresponding changes in physical properties may be expected to occur, a phase of the subject which will be discussed later in the paper. Yarn stretched in the dry state even to its breaking point does not reach the limit of structural order that can be obtained if the molecular chains are given a little freedom so that greater mobility is allowed during stretching. Such freedom may be provided by the thermal effects of elevated temperatures, by means of chemicals which break the hydrogen bonding between adjacent chain molecules, or by a combination of both of these. Under proper conditions the molecular chains become sufficiently mobile to allow the crystalline areas formed among them to orient to an even greater degree than is possible by dry-stretching. Once having been oriented to the desired degree, the agent which allowed limited freedom and mobility may be removed and the chain molceules trapped in the new positions. The right half of Figure 6 illustrates the x-ray diffraction diagram of cellulose acetate yarn which has been given the same amount of stretch as that dry-stretched at room temperature, but done under conditions allowing mobility. The left half of the split diagram is from dry-stretched yarn and is included for purposes of comparison. In the right half there is shown a greater tendency for the inside circle to concentrate at one spot and for the rest of the circle to become darker. This indicates that the crystalline areas, few and irregular as they are, have become more oriented relative to the fiber axis than the same areas of the dry-stretched yarn. However, in neither case have the arcs or light areas tended to sharpen, as in the diagram of the original material, which indicates that the crystallinity has not increased to any great extent. Thus it is concluded that the steric effects of heterogeneous groups as side chains on the molecules are not overcome by the orienting produced by stretching under either dry conditions or under conditions that allow molecular mobility.

It is possible to obtain an even greater amount of orientation. This may be done by (1) maintaining the conditions which allow molecular mobility, (2) controlling the rate of stretching which produces

orientation, and (3) properly removing the conditions which originally allowed mobility. This last must be so arranged that the orientation does not become lost. Examples of the increase in orientation produced by treating yarns in such a manner are illustrated in the x-ray diagrams given in Figures 7 and 8. In the former, the arcs tend to concentrate into spots to a greater degree than is illustrated in the right half of Figure 6. In the original film from which Figure 8 was prepared it is possible to see faint traces of arcs, which cannot be seen in the original of Figure 7. But, as before, the change in the structural order is limited to orientation and no appreciable change in crystallinity can be observed.

Cellulose Yarn

As previously mentioned, in the case of cellulose triacetate, uniformity of side groups on the molecular chains makes possible greater regularity of packing and association, and therefore greater crystallinity, than is the case where there is nonuniformity as in the commercial secondary cellulose acetate used in the manufacture of textile yarns. By removing all of the acetyl groups from cellulose acetate by saponification of cellulose acetate yarn, an even greater degree of crystallinity may be achieved than is possible by annealing the triacetate. Figure 9 is the x-ray diffraction diagram of cellulose regenerated from commercial cellulose acetate yarn. In it the rings are very sharp as compared with those in the diagram of the cellulose acetate yarn from which the cellulose was regenerated. Not only is the crystallinity of a higher order, but it is obvious that there is some slight tendency for the rings to form into arcs. This beginning of orientation, present in the yarn as normally spun, may be compared with that obtainable from cellulose yarn regenerated from the cellulose acetate yarn previously stretched to just below its breaking point, this latter being illustrated in Figure 10. In such stretched yarn the crystallinity is the same as that in the original unstretched material but there is slightly more orientation. Figure 10, which is the characteristc x-ray diagram of native cellulose, also illustrates that the regeneration process can be so regulated as to produce either native or mercerized cellulose without disturbing the orientation originally placed in the cellulose acetate. As the orientation in the cellulose acetate fibers is progressively increased by producing it under conditions of limited molecular segment mobility and stretching, the cellulose fibers resulting therefrom are correspondingly oriented. Figures 11, 12, and 13 illustrate this phenomenon. In this series, the rings first tend to become arcs and these in turn

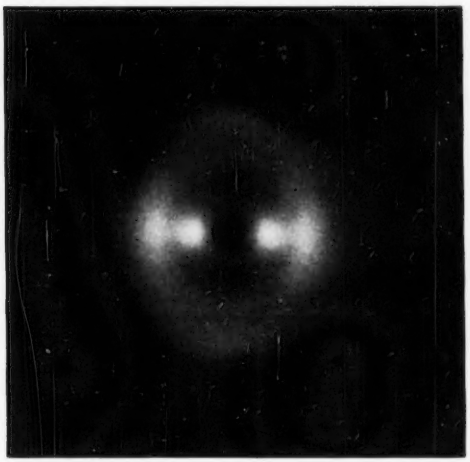

FIG. 7. *X-ray diffraction pattern of cellulose acetate yarn stretched to a greater degree when swollen than the sample illustrated in Fig. 6 (right).*

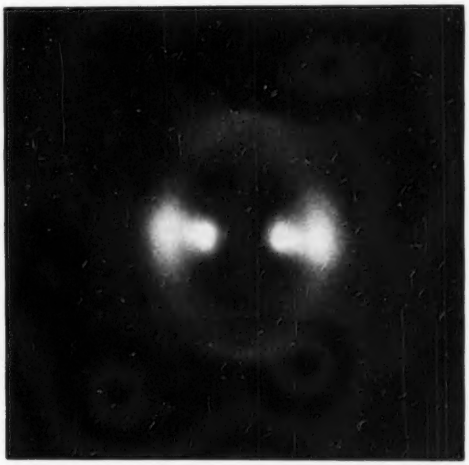

FIG. 8. *X-ray diffraction pattern of sample similar to that illustrated in Fig. 7, with greater amount of stretching.*

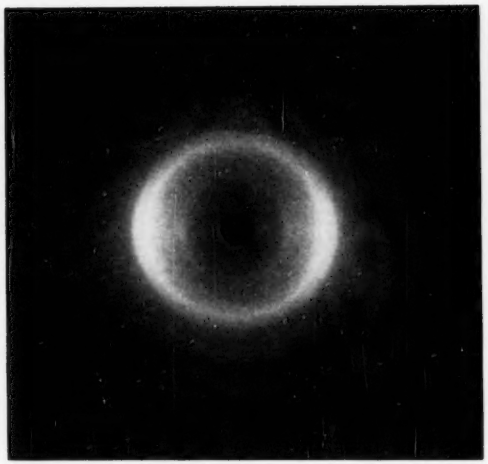

FIG. 9. *X-ray diffraction pattern of cellulose regenerated from the cellulose acetate of Fig. 4.*

narrow down in a trend toward becoming spots. In Figure 13 there is a sharpness which reminds one of the rotation pattern of an inorganic crystal such as common salt. In it crystallinity and orientation are illustrating a degree of structural order in a textile fiber that has been carried to an extreme point.

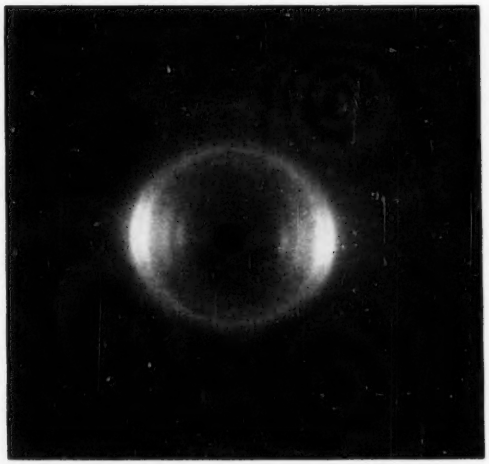

FIG. 10. *X-ray diffraction pattern of cellulose regenerated from the cellulose acetate of Fig. 5.*

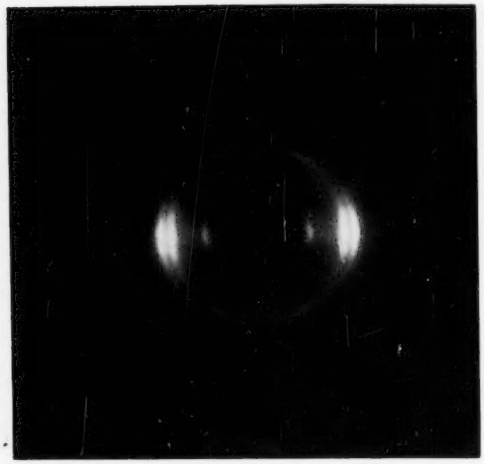

FIG. 11. *X-ray diffraction pattern of cellulose regenerated from the cellulose acetate of Fig. 6 (right).*

Structural Order as Related to Load-Elongation Properties

Changes in physical properties of cellulose acetate and cellulose fibers are to be expected when the degree of structural order is changed, be that by variation of crystallinity or orientation. In the case of these materials, as is illustrated by the x-ray diffraction diagrams, little can be done to control the crystallinity. The secondary cellulose acetate used for textiles cannot be made to crystallize more than to a very small degree, and cellulose can be prevented from doing so only under special conditions that need not be discussed here. Certain other materials are more amenable to control of crystallinity and some have been subjected to detailed study [1, 2, 4].

However, for the study of the effects of orientation, both cellulose acetate and the cellulose regenerated from it are excellent materials, for the amount may be changed progressively and in a relatively simple manner. It is only necessary to place the cellulose acetate yarn of commerce in a swelling agent—for example, in a mixture of dioxane and water [3]—stretch to the desired degree in the swollen condition, and follow by removal of the swelling agent by washing or evaporation. The oriented cellulose acetate thus produced may be

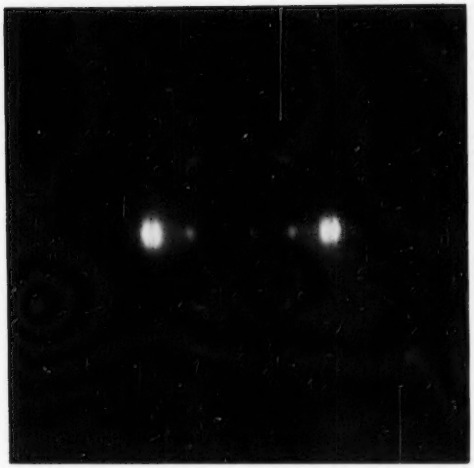

FIG. 12. *X-ray diffraction pattern of cellulose regenerated from the cellulose acetate of Fig. 7.*

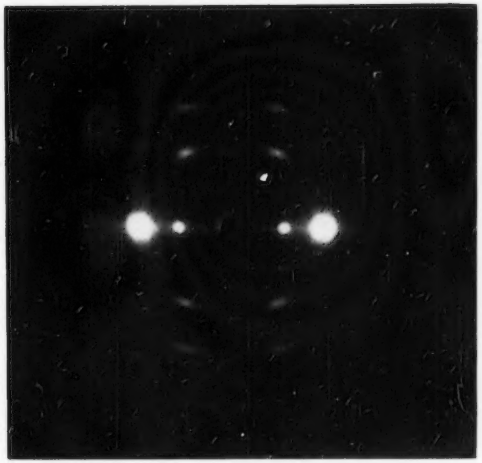

FIG. 13. *X-ray diffraction pattern of cellulose regenerated from the cellulose acetate of Fig. 8.*

saponified by the usual alkaline chemicals to become a correspondingly oriented cellulose yarn.*

By varying the orientation in these yarns, there are changes in physical properties, of which the load-elongation relationships are both important and easy to determine. In Figure 14 there is shown a representative family of load-elongation curves of cellulose acetate of no orientation, and of the same material after it has been oriented to varying degrees. The change in properties from those of the unorientated material as orientation is increased through the series 1 to 5 shows a large decrease in elongation which tends to reach a limiting value. At the same time, the tenacity increases enormously.

Based on the x-ray diagrams of this series of yarns, such behavior would be expected. More and more of the crystalline areas where lateral order of sections already exists become oriented with the lengthwise directions of the chain molecules tending to become parallel to the fiber axis. From its structure it is known that the cellulose skeleton will not elongate appreciably. As a result, the fibers comprising the textile yarn have a corresponding ability to resist stretching. Likewise, the molecular chains become oriented to an increasing degree parallel to the fiber axis and to the vectors of force stressing the yarn. The molecular chains thus support more of the load with less of the stress tending to separate adjacent molecules, this last being the ultimate cause of failure.

The only change of order in the group of cellulose acetate yarns which was the basis of Figure 14 was orientation relative to the fiber axis and the yarns were tested by applying stress in that same direction. There was no apparent change in crystallinity. But, as has been illustrated by x-ray diffraction diagrams, saponification of secondary cellulose acetate to cellulose causes a great increase in crystal-

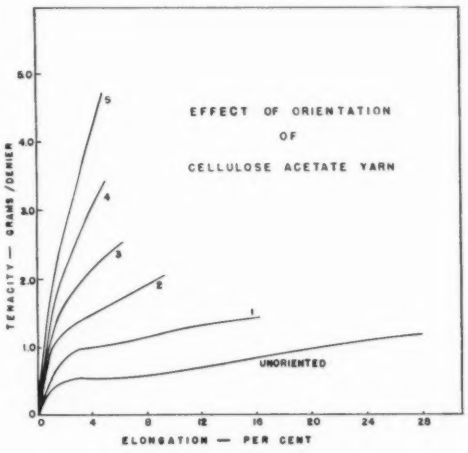

FIG. 14.

* A discussion of oriented cellulose yarns produced by the viscose process will be found in [7].

linity with no apparent decrease in orientation, if done under proper conditions. When such saponification is carried out on a series of oriented cellulose acetates, a corresponding series of regenerated cellulose yarns is secured which has the load-elongation characteristics shown in the representative family of curves illustrated in Figure 15. These curves are quite similar to those for oriented cellulose acetate in that there is the same enormous increase of tenacity and decrease in elongation with orientation. But the tenacity of the whole family has increased in the cellulose yarns. The differences between the two series can be better shown if the breaking tenacities and elongations of each are connected by curves as is shown in Figure 16. A comparison of the curves shows that the increase in crystallinity* produced by converting cellulose acetate to cellulose has increased the tenacity throughout the entire range of orientations. The elongation at break changes but a very little where the orientation is small, and levels off, or even increases, as the maximum orientation is attained. This last is apparently due to the greater lateral order which comes with the increased crystallinity of cellulose as compared with the cellulose acetate. As a result of the greater association of segments of the chain molecules, greater forces are required to separate adjacent chain molecules. The increase in tenacity is so great in the region of high orientation where the cellulose chains are carrying the stress that a small amount of further elongation is contributed to these particular materials.

Lateral Strength as a Function of Orientation

It is not within the scope of this paper to discuss to any great length the axial load-elongation properties of these textile yarns. Rather, it is of interest to consider their lateral physical strengths. However, there are no techniques sufficiently delicate to grasp opposite sides of a single filament and break it by pulling perpendicular to the fiber axis. Therefore, another approach must be used to gain some insight into the effect of orientation on lateral strength. This may be done by subjecting the fibers to a crushing and battering action in a completely random manner and examining the resultant products by means of the electron microscope.

When cellulose acetate yarn is so crushed and broken, the particles obtained show no failure in any preferred direction, but rather have the appearance that would be expected to result from attrition of an amorphous material. Figure 17 illustrates such particles. The results that are obtained with saponified cellulose acetate yarn are shown in Figure 18. Without identification it would be difficult to tell

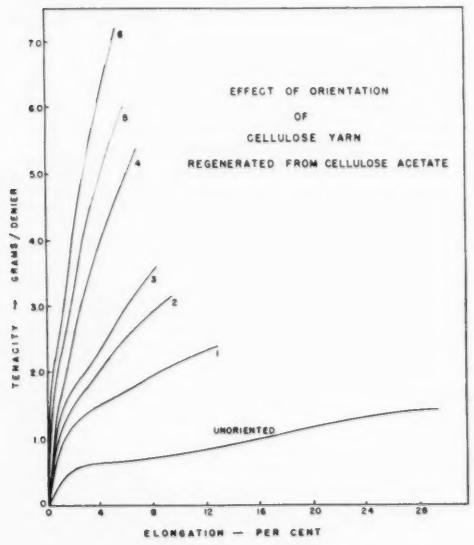

FIG. 15.

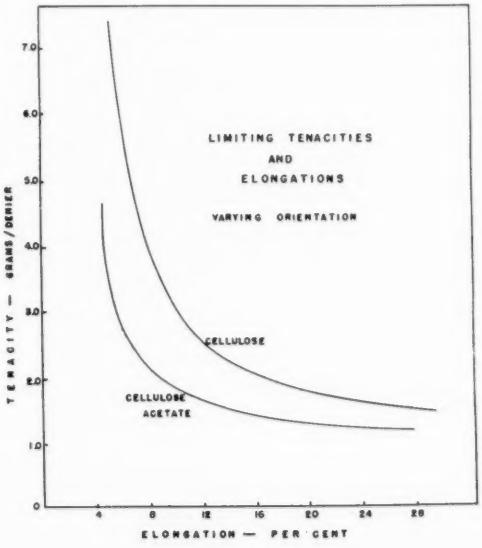

FIG. 16.

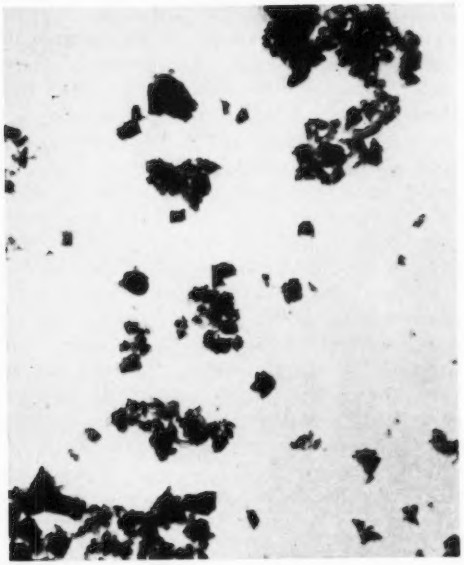

FIG. 17. *Electron micrograph of ground cellulose acetate filament.*

FIG. 18. *Electron micrograph of ground cellulose regenerated from the cellulose acetate of Fig. 17.*

these two electron micrographs apart, and the explanation of the first applies to the second as well. However, when oriented cellulose acetate yarn is broken up by attrition and the particles are examined under the electron micrograph, there is evidence of failure parallel to the fiber direction and a resulting tendency to produce fibrillae (Figure 19). When the cellulose acetate is first highly oriented, saponified to cellulose, and then disintegrated, an enormous change takes place in the appearance of the particles, as is seen in Figure 20. All of the material tends to be filamentous in nature and the pieces are no longer similar to the small irregularly-shaped particles illustrated in Figures 17 and 18 of the two unoriented fibers. From these electron micrographs only qualitative observations may be made as to the ratio of longitudinal strength to the lateral strength of fibers as structural order is varied. However, it may be seen that without orientation no fibrillation takes place, indicating that the fibers are equally strong in all directions. When orientation and high crystallinity are combined, most of the failure tends to be parallel to the fiber axis, producing long fibrillae. That strength which has been gained in the fiber axis has been lost perpendicular to it. No other result would be expected.

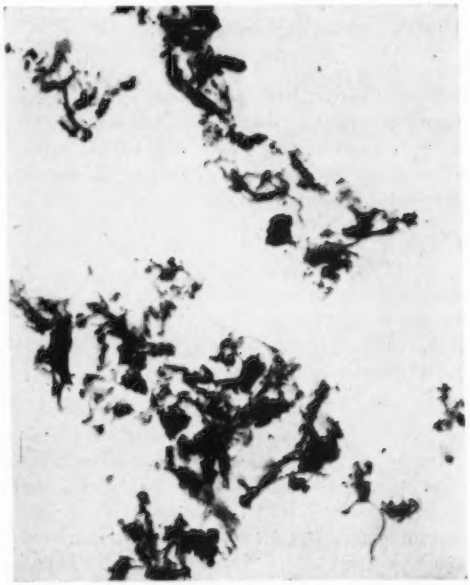

FIG. 19. *Electron micrograph of ground oriented cellulose acetate textile filament.*

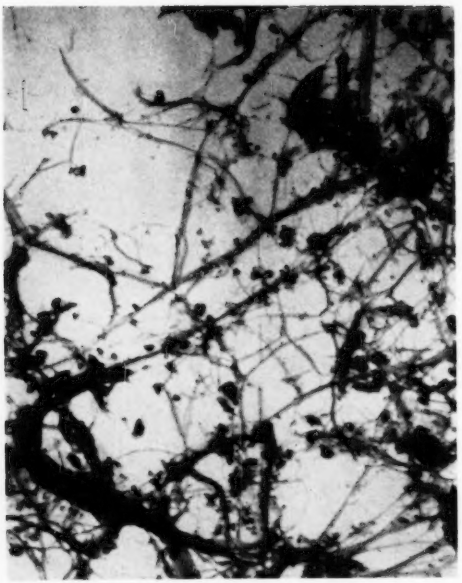

FIG. 20. *Electron micrograph of ground cellulose regenerated from the cellulose acetate of Fig. 19.*

The Effects of Varying Structural Order on Sonic Moduli

Referring back to the load-elongation properties of cellulose acetate yarns and cellulose yarns regenerated from them, it is generally agreed that the individual curves of Figures 14 and 15 are the resultants of three components:

1. The instantaneous deformation, which is totally elastic and immediately recoverable.
2. The primary creep, which is also elastic but is only slowly recoverable.
3. The secondary creep, which is a flow and is not recoverable.

Each load-elongation curve combines the total of these components for a given material elongated during a given time interval. As is well known, such curves will vary in shape with the time period used, since both the primary and secondary creep components are time-dependent. The elastic component is not time-dependent and can be compared to the elastic deformation of metals that occurs in the Hookean region of elongation. The behavior of a body in this elastic region is defined by the modulus of elasticity, which is the ratio of the internal stress to the strain giving rise to it. This modulus is easy enough to measure both in the case of metals and in textiles. But it is difficult to measure under dynamic loading conditions and to determine the immediate elastic component of deflection. Only by reducing the time interval during which the fiber is deformed to a very short period is it possible to approach the elimination of the effect of creep.

Recently [6] a device known as the "pulse propagation meter" has been developed to make such measurements possible. Briefly, it makes use of two piezo crystals across and in contact with which the specimen to be tested is held. Tension can be increased up to the breaking point of the yarn or fiber while the measurements are being made, if so desired. A pulse is impressed upon the sample by one of the piezo crystals and this pulse is picked up by the second crystal upon arrival. The actual duration of the deformation of the yarn resulting from the pulse is not accurately known but it is probably of the order of one ten-thousandth to one hundred-thousandth of a second, and accordingly is very far in the desired direction of deforming the sample being tested for zero time. By means of appropriate electronic equipment the time elapsed between the propagation of the pulse and its reception is measured, and this is recorded by the device.

The formula which relates the velocity of sound to the density and modulus of elasticity is

$$V = \sqrt{\frac{E}{d}}.$$

The density, d, of the yarn is known, and the velocity, V, of sound can be calculated from the known length

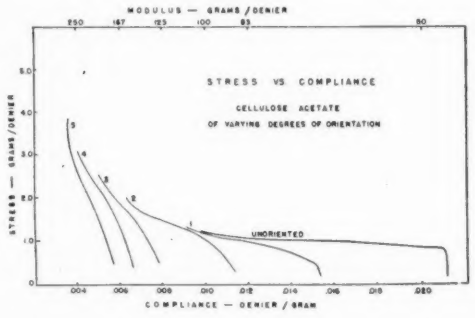

FIG. 21.

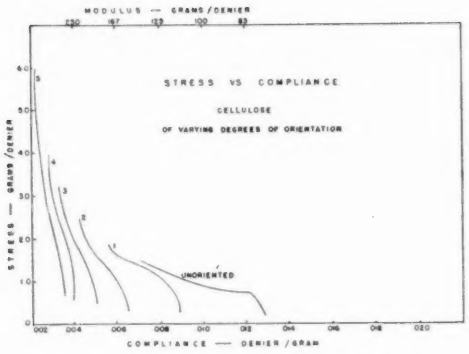

FIG. 22.

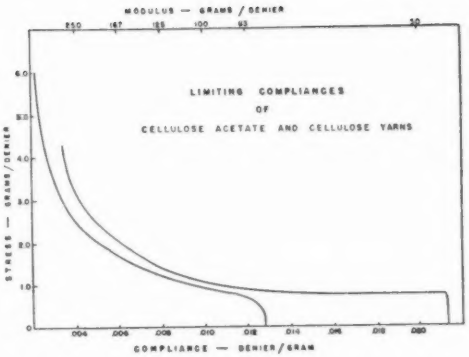

FIG. 23.

of the yarn between the two crystals and the length of time required for the pulse to travel that distance. The distance between the crystals being constant, for any given test the modulus will be a function of the square of the time required for the signal to pass from the first to the second crystal. This makes the calculation of the modulus, E, a simple one. It is possible to express this property of the materials either as the modulus in grams per denier, or as the compliance in denier per gram—that is, the inverse of the modulus.

By means of this pulse propagation meter, measurements have been made of the moduli of elasticity of the various yarns—both cellulose acetate and cellulose regenerated from cellulose acetate—of varying degrees of structural order. Such moduli have been determined under conditions of continuously increasing stress up to the points of failure. A representative family of curves obtained by this technique is illustrated in Figure 21, in which the numbers 1 to 5 indicate increasing orientation. Although at the time when these data were obtained it was not possible to make the measurements under zero stress since the yarns must be placed in good contact with the crystals and a slight tension applied, it will be seen that the stress-compliance curves of the yarns, when extrapolated to zero stress, vary widely in compliance (and modulus). The ratio of the compliance of the unoriented material to that of the most completely oriented of this series is of the order 3½ to 1. Of equal interest is the manner in which the compliance decreases as the yarns are elongated under increasing stress. Stretching decreases the compliance, the effect being considerably greater with the unoriented parent material and the yarns of lower original orientation than with the more oriented members of the series. There is a tendency for the curves to overlap each other. However, those on the right are seen to fail before the compliance reaches that of the more oriented materials.

When a series of cellulose acetate yarns of varying orientation are saponified to produce corresponding regenerated cellulose yarns, a family of stress-compliance curves may be secured from them, such as is illustrated in Figure 22. Here again the compliance of the extremes extrapolated to zero stress is in a ratio of about 3½ to 1 and, as in the previously discussed case, as the yarns are subjected to continuously increasing stress up to their breaking points, the compliance of the less oriented tends to approach that of the more oriented. With the most oriented, as also in the previous case, there is comparatively little change in compliance of the yarn when subjected to low stress up to breaking stress. When the compliances at breaking stresses of all members of each of these two families of curves are connected and plotted on a single graph (Figure 23) it can be seen that the moduli at failure of the series of cellulose yarns are higher throughout the range of varying degrees of orientation, thus illustrating the effect of changing the structural order by increasing the crystallinity.

Both varying orientation and crystallinity as related to modulus are of interest from a basic standpoint. When deformation of any material is below the elastic limit (which deformation by definition is instantaneously recoverable) the substance returns to its original physical shape when stress is removed.

It may therefore be assumed that the total deformation is of such character that the individual atoms, groups of atoms, and molecules which make up the material are not so moved by the stress that they are no longer able to provide the restoring forces that originally held them in those positions relative to each other that existed in the unstressed state. To put it another way, it can be said that the material will not return to its original shape if enough energy has been supplied to overcome the associational forces between the atoms and molecules in the substance. With increasing order—either that which has been described as crystallinity or as orientation—the adjacent atoms and molecular segments are held in their positions by greater forces. This being the case, the modulus of elasticity—that is, the force required to move them relative to each other and so produce a given elastic deformation—will increase to a corresponding degree in a series where the degree of order becomes more perfect by either increasing orientation or crystallinity. Thus orientation, produced by any method, increases modulus, as does also increasing crystallinity. Up to this time, x-ray diffraction techniques have been used to study these phenomena. However, the sonic moduli measurements appear to be more sensitive to the variations in orientation and possibly in crystallinity.

At this time it is desirable to draw only limited conclusions from these studies of sonic moduli of textile fibers. From Figures *21* and *22* it would appear that there are limitations to the regularity that can be achieved in both cellulose acetate yarns and cellulose yarns regenerated therefrom. In the family of curves for cellulose acetate, the upper part of each curve of a material of lower orientation tended to overlap the curve of next higher orientation. However, with the regenerated cellulose each curve tended only to approach the next, failure occurring before overlapping took place. It has been suggested by Dr. Hamburger * that this difference illustrates the behavior of a mostly amorphous high polymer as compared with a more crystalline substance. The former tends to flow, whereas the latter resists flow and possibly becomes more crystalline as the result of deformation. Since this is a recent technique, more will be learned as further research is carried out in this field.

* Personal communication.

Observations on One Aspect of Structural Order of Cotton

The dye acceptance of either cellulose acetate or cellulose yarns is another physical property which is a function of the degree of structural order of these materials. The subject is an enormous one but one small phase of it is of immediate interest and will be mentioned here since it has both basic research aspects and practical importance.

Some time ago, Goldthwait and his associates at the Southern Regional Research Laboratory of the U. S. Dept. of Agriculture discovered that when cotton is dyed with a mixture of Diphenyl Fast Red 5 BL Supra I (Geigy) and Chlorantine Fast Green BLL (Ciba) and then soaped to remove the dyes, the immature fibers remain preferentially dyed green and the mature fibers remain dyed pink [5]. This phenomenon is of importance in the grading of cotton, for it is desirable to know the amount of immature fiber present in a sample.

It is well known that the thickness of the secondary wall is one criterion that differentiates mature and immature fibers, but this is hardly an adequate explanation of differences in dye retention. Rather, there must be a more basic reason. The fact that the molecules of the green dye are about twice as big as the molecules of the pink dye directs one's attention to the aspect of available space among the molecules of cellulose in cotton. The varying degree of order that may be produced in cellulose regenerated from cellulose acetate gives the basis for an approach from this direction. As already described, orientation may be produced by stretching cellulose acetate under either of two conditions. The first of these is by ordinary dry-stretching and the second is by stretching under the conditions where limited mobility of molecular segments is allowed by swelling agents. The resulting two series of yarns are then saponified to cellulose and dyed with a mixture of the two dyes already named. All of the samples are then soaped equally to remove loosely-held dye, washed, and dried. It is found that the original unoriented fibers are colored green whereas the samples stretched either dry or in the swollen condition have become pink. The progression from green to pink is more rapid in the series stretched when swollen. The comparison of the two series is seen in Figure *24*.

Based on these preliminary observations, it may

COTTON

IMMATURE MATURE

SAPONIFIED CELLULOSE ACETATE YARN

STRETCHED WHEN DRY

STRETCHED WHEN SWOLLEN

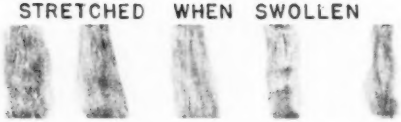

Fig. 24.

be suggested that mature and immature cotton fibers differ in their degrees of order (probably orientation). The general conclusion may be drawn that differential dye-retention of closely related fibers is a valuable tool for fundamental research on such material. Conversely, from the practical viewpoint, where differential dyeing occurs and is a source of difficulty it is well to look to varying structural order for a possible cause.

Thus it is seen how research on the basic physical properties of the more recently developed textile fibers may contribute to a better understanding of cotton, one of the oldest fibers. Differences in dyeing behavior of supposedly identical fibers, long known by practical textile men, become a tool in research. Modern techniques which involve the use of the x-ray diffraction-spectrograph, the electron microscope, and more recently, the pulse propagation meter contribute to the fuller understanding of fibers. Out of the interplay of all of these techniques the textile industry advances.

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(*Manuscript received April 25, 1949.*)

An Improved Multipurpose Abrasion Tester and Its Application for the Evaluation of the Wear Resistance of Textiles*

R. G. Stoll†

Contribution of the Quartermaster Textile Laboratory

Abstract

On the basis of a systematic consideration of the mechanics of fabric wear and abrasion and extensive experimentation with various test methods and machines an improved multipurpose abrasion tester has been developed under the research program of the Quartermaster Corps. This work was carried out jointly by the Quartermaster Textile Materials Engineering Laboratory and the Textile Section of the National Bureau of Standards. The apparatus is capable of quantitatively measuring resistance to flat-, edge-, and flex-abrasion under carefully controlled conditions, producing macro- and micro-wear patterns which are the same as those obtained in actual wear. Materials tested in the machine are abraded to an endpoint which is quantitatively defined and independent of individual judgment. Deviations in test results due to the machine are insignificant compared to the deviation of the samples themselves. A correlation has been found to exist between accelerated combat-wear data and results obtained on the new tester.

I. Introduction and Problem

During the past twelve years methods for evaluating the durability or wear resistance of fabrics have been the subject of numerous investigations [2, 9, 16, 24]. These studies have served to clarify the hitherto rather confused terminology used in considering the durability and wear resistance of textiles, and have also laid the groundwork for further research by indicating the method to be followed in attacking the problem as a whole. The results of the previous investigations also demonstrate that the durability of textile materials is determined by a great number of destructive, disintegrating, and degrading physical and chemical actions to which they may be subject. These actions vary considerably according to the use of the material [2, 17, 21, 22]. It is neither possible nor necessary to consider every wear factor which can be isolated for a specific use. Instead, attention need be given only to those actions found to be critical as a result of service tests and salvage studies [10]. Although qualitative classifications of the importance of the various wear factors of textiles for specific purposes have been presented [21], our quantitative conceptions of the relative significance of these factors from the standpoint of over-all serviceability are still based largely on guesswork.

A. Composition of Wear

The results of more recent salvage analyses conducted by the Office of The Quartermaster General on large series of field uniforms [23] indicate that in normal wear the mechanical factors of actual destruction and gradual disintegration can be divided approximately as follows: 30 percent plane abrasion, 20 percent edge and projection abrasion, 20 percent flexing and folding, 20 percent tear, and 10 percent other mechanical actions. Similar relations have also been derived in other investigations for civilian garments in general [14]. It has also been found,‡ however, that the relative importance of the wear factors can be of a very different order due to specific intrinsic properties of the fiber material. For rayon and rayon-blended fabrics in comparison with

* Based upon Textile Series Report No. 54, Office of The Quartermaster General, 15 March, 1949.

† Textile Development Engineer, Textile Materials Engineering Laboratory, Philadelphia Quartermaster Depot.

‡ Unpublished results of investigations performed by the author as part of a research program of the Suddeutsche Zellwolle AG, Kelheim (South German Rayon Company, Inc.) on serviceability of rayon.

cotton, for example, the resistance to plane abrasion in a wet condition and to flex abrasion in a dry state are the critical wear factors in many applications. In the case of resin-treated fabrics, edge abrasion in connection with flexing and folding becomes of the highest relative importance for many uses. The figures on the relative importance of the wear factors obtained by salvage analysis of service tests may also require correction, since it is impossible to obtain visually, even with the aid of a microscope, a quantitative analysis of all the factors which contribute to a given failure. In the formation of a hole apparently caused by plane abrasion, for example, other factors may also have been partially responsible, such as tearing or the unevenness of the fabric. Nevertheless, these qualitative and semiquantitative analyses and deductions indicate consistently that as far as mechanical disintegration of the fabric and yarn structure and gradual breaking up of the individual fiber are concerned, the following must be considered as major wear actions: (*a*) plane or flat abrasion; (*b*) abrasion on edges, folds, and projections; (*c*) abrasion by flexing and bending. The relative resistance of comparable samples to these three wear actions can be of a different order.

In general, therefore, it is impossible to test mechanical disintegration with one type of abrasion. Nor can an attempted combination of the three types of abrasion in one complex test action be recommended, since their relative importance is dependent upon the specific use for which a given fabric is intended and the raw material from which it is made. From the viewpoint of controlling the mechanics of the test actions it is also preferable to test the different abrasions separately rather than in combination.

B. Three Basic Cohesive Forces Determining Abrasion

The mechanical reactions of fabrics to all three abrasion actions are determined by the same three cohesive forces [12], namely: (*a*) cohesion between the abrasive and the fiber; (*b*) cohesion between contiguous fibers; (*c*) cohesion between the structural parts of the fibers themselves. It should be possible therefore, theoretically at least, to predict the resistance of textiles to the various types of abrasion on the basis of the inherent and geometrical properties of the fiber material, the form factors of the yarn and fabric structures, and the frictional forces between the fiber or fabric and various abrasives. Some approaches in this respect have already been made [1, 8, 10, 25]. However, the mechanics of these actions and reactions are so complex and so incompletely understood that the study of these basic cohesion properties cannot replace the use of adequate instruments to measure the abrasion resistance of fabric samples on the basis of isolated test actions, such as plane abrasion, edge abrasion, and flex abrasion.

C. Abrasion Conditions

All three types of abrasion have a number of conditions in common which more or less significantly influence the degree of gradual destruction which takes place. Among these are the following: (*a*) general conditions, such as abrasion, wet abrasion, or abrasion under other specific functional conditions; (*b*) nature of abradant; (*c*) pressure on the sample and tension of the sample; (*d*) direction and speed of the motion; (*e*) removal of lint and other debris. Variation in these abrasion conditions can easily cause a larger deviation in the test response than that due to difference among the samples, thus invalidating the results of an entire test.

D. Abrasion Resistance

Another fundamental problem of equal importance for all types of abrasion is the definition and measurement of the abrasion resistance. The relative and absolute resistance of a fabric to a specific abrasion action is best expressed by the ratio of the quantity of abrasion action (represented by an energy or a relative value for that energy) to the quantity of abrasion. The quantity of abrasion should be measured in terms of the volume or weight of the material removed by attrition or as the area of the cross section which has been completely disintegrated by the test action. It may not be necessary that an isolated test action duplicate precisely a specific wear action [10, 13], but the former must produce a mechanical disintegration which is comparable to the actual wear pattern [5, 12].

On the basis of this systematic consideration of wear and abrasion factors and of a long practical experience with various commercial and experimental abrasion machines, an improved multipurpose abrasion tester has been developed jointly with the Textile Section of the National Bureau of Standards

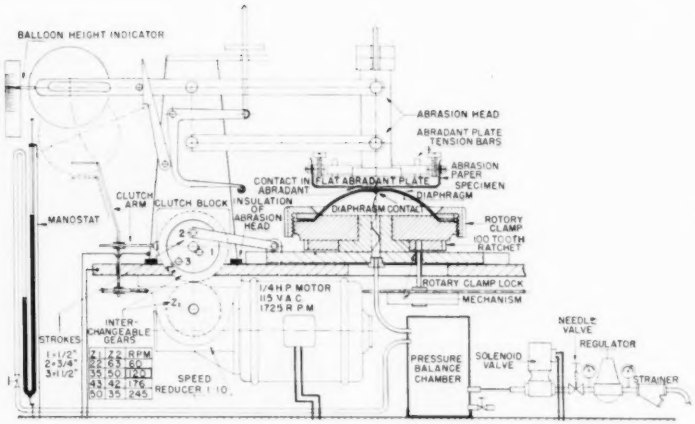

FIG. 1. *Diagram of a tester showing flat-abrasion attachment.*

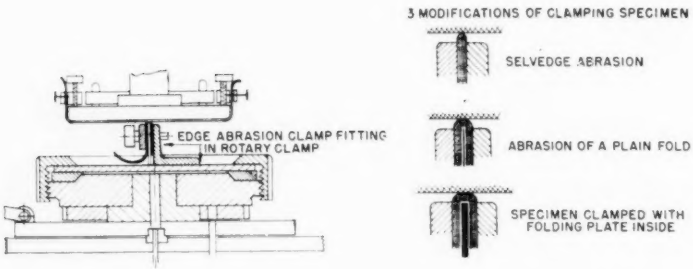
EDGE ABRASION CLAMP FITTING IN ROTARY CLAMP
3 MODIFICATIONS OF CLAMPING SPECIMEN
SELVEDGE ABRASION
ABRASION OF A PLAIN FOLD
SPECIMEN CLAMPED WITH FOLDING PLATE INSIDE

FIG. 2. *Diagram of edge-abrasion attachment.*

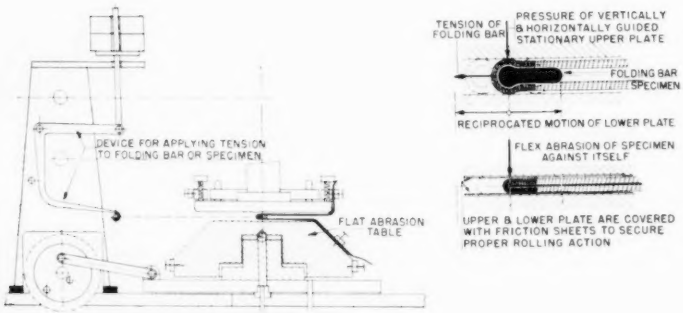
DEVICE FOR APPLYING TENSION TO FOLDING BAR OR SPECIMEN
FLAT ABRASION TABLE
TENSION OF FOLDING BAR
PRESSURE OF VERTICALLY & HORIZONTALLY GUIDED STATIONARY UPPER PLATE
FOLDING BAR SPECIMEN
RECIPROCATED MOTION OF LOWER PLATE
FLEX ABRASION OF SPECIMEN AGAINST ITSELF
UPPER & LOWER PLATE ARE COVERED WITH FRICTION SHEETS TO SECURE PROPER ROLLING ACTION

FIG. 3. *Diagram of flex-abrasion attachment.*

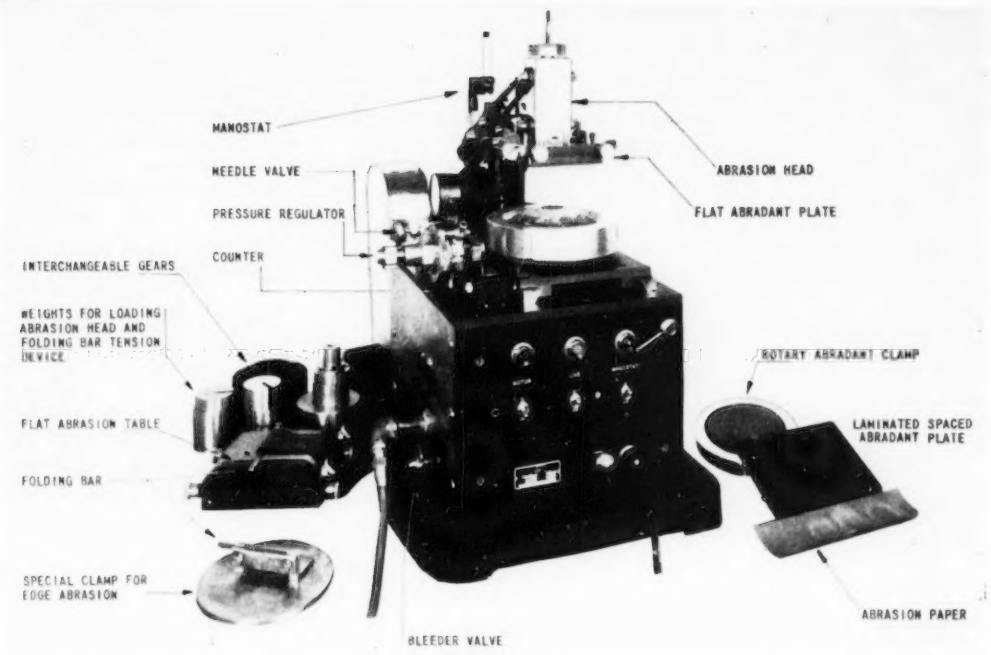

FIG. 4. *Front view of tester showing flat-abraded fabric in pneumatically controlled rotary sample clamp.*

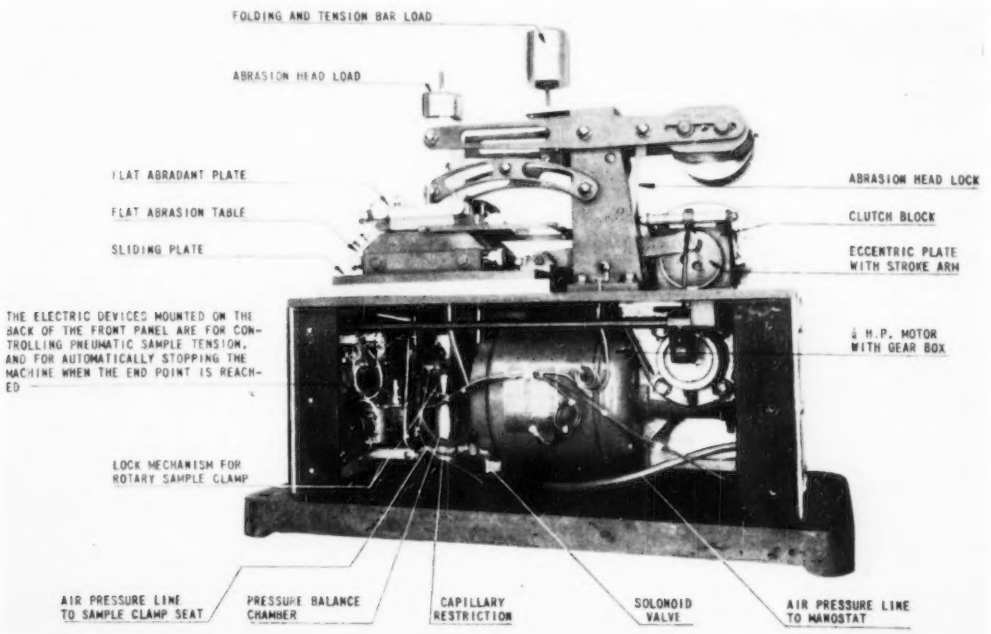
FOLDING AND TENSION BAR LOAD
ABRASION HEAD LOAD
FLAT ABRADANT PLATE
FLAT ABRASION TABLE
SLIDING PLATE
THE ELECTRIC DEVICES MOUNTED ON THE BACK OF THE FRONT PANEL ARE FOR CONTROLLING PNEUMATIC SAMPLE TENSION, AND FOR AUTOMATICALLY STOPPING THE MACHINE WHEN THE END POINT IS REACHED
LOCK MECHANISM FOR ROTARY SAMPLE CLAMP
AIR PRESSURE LINE TO SAMPLE CLAMP SEAT
PRESSURE BALANCE CHAMBER
CAPILLARY RESTRICTION
SOLONOID VALVE
AIR PRESSURE LINE TO MANOSTAT
ABRASION HEAD LOCK
CLUTCH BLOCK
ECCENTRIC PLATE WITH STROKE ARM
¼ H.P. MOTOR WITH GEAR BOX

FIG. 5. *Side view of tester (panel removed) showing flex abrasion with folding and tension bar.*

as part of the wear resistance project of the Quartermaster Textile Materials Engineering Laboratory. A model of this machine has been constructed by the American Instrument Company, Silver Spring, Maryland. The tester is capable of producing the three major types of mechanical wear in various modifications and under carefully controlled conditions. Many of the finer points in the constructional details of this instrument have been developed as a result of experimentation on previous models with hundreds of samples [21, 22]. This experience has proved to be as important to the precision of the machine as consideration of the basic principles of the abrasion factors.

II. Description of the Machine

The machine consists of eight main parts: framework, driving mechanism, abrasion head, pneumatically controlled rotary sample clamp mechanism, pneumatic tension control system, special edge abrasion clamp, flat abrasion table with tension and folding device, and electric devices for pressure control and endpoint stop.

The principle of the construction of the apparatus and the method of testing flat, edge, and flex abrasion are indicated in schematic diagrams shown in Figures 1, 2, and 3. Two photocomposites of the apparatus and its different interchangeable parts are shown in Figures 4 and 5.

A. Framework

All the main parts of the apparatus are assembled on a steel plate which is supported by five angle irons mounted on a heavy base plate. The framework is enclosed by removable panels. The front panel serves as control board, with the electric devices mounted on the rear side.

B. Driving Mechanism

A $\frac{1}{4}$-H.P., 115-Volt A.C. motor with a 1:10 speed reducer drives a crank disk by a pair of interchangeable spur gears and a clutch, and a sliding plate by a connecting rod. The plate is guided by dovetail sliding strips. The reciprocal motion of the sliding plate may be operated at 60, 120, 176, and 245 double strokes per minute. (A suitable speed for most tests has been found to be 120 strokes per minute.) The stroke length can be set at $\frac{1}{2}$ inch, $\frac{3}{4}$ inch, and $1\frac{1}{2}$ inches. The last length has been determined as most suitable for flat and edge abrasion, while the $\frac{3}{4}$-inch length is most practical for flex abrasion. The mechanical clutch provides a means for immediately stopping a test at any time without shutting off the motor. The clutch is disengaged either by operating a handle on the front panel or by lifting the abradant plate. The number of double strokes of the sliding plate is indicated by a counter which records the quantity of abrasion action, since in all applications of the instrument this action will always be proportional to the number of strokes.

C. Abrasion Head

A bracket, electrically insulated against the upper base plate, supports a structural lever assembly in ball bearings. This double-lever parallelogram guides the abradant plate in an exact horizontal position and permits its vertical movement under a load which can be precisely balanced. The abrasion head is insulated against the other parts of the machine so that upon complete abrasion or rupture of the specimen the machine is stopped immediately by contact. The following three different types of abradant plates fit into the abrasion head post and can be easily interchanged:

(*a*) A flat abradant plate which is normally used in all three types of tests. This plate is provided with adjustable clamps on each side for holding the abrasion material (abrasion sheets or strips of fabric) in a stretched position. A contact pin is inserted on the lower side of the plate on the length axis at the turning point of the rotary clamp (see *D* below). This pin extends through a hole of the same diameter which is made in the abradant at this point. The pin is adjustable to the thickness of the abradant.

(*b*) A laminated spaced abradant plate similar to the clock-spring abradant used on the Schiefer testing machine [15].

(*c*) A rotary abradant clamp which can be rotated manually. This clamp, particularly suitable for fabric-on-fabric abrasion, also permits changing both the portion of the abradant in contact with the specimen and the direction of abrasion.

D. Pneumatically Controlled Rotary Sample Clamp Mechanism

The body of the clamp consists of a round plate and a 100-tooth ratchet gear mounted on a flange

attached to the reciprocating plate. At the end of each double stroke the clamp is turned slightly—a distance equal to 1, 2, or 3 teeth of the ratchet gear—by an adjustable pawl mechanism assembled on the sliding plate. The specimen is mounted on top of the round plate over a rubber diaphragm by means of a retaining ring and a tightening collar. Two different rings are provided with the clamp, which permit testing over a clamped area of 50 or 100 sq. cm. as desired. When installing or removing the specimen, the rotary clamp can be locked by a special safety device which is coupled with the clutch of the driving mechanism and which simultaneously releases the pawl from the ratchet gear. If it is desired to abrade the specimen in one selective direction only, the pawl can be released by means of a button on the front panel. The diaphragm is inflated by a controlled air pressure which is introduced through a flange by a flexible hose connected to the sliding plate. A contact pin is mounted in the center of the diaphragm to provide an automatic end-point stop for flat-abrasion tests using the pneumatically controlled rotary sample clamp. A thin spring wire sliding in the orifice of the flange makes contact with the grounded parts of the machine when the specimen is completely abraded.

E. Pneumatic Tension Control System

A constant air-pressure control which can be regulated from 0- to 6-lbs.-per-sq.-in. pressure as required in the tests is accomplished by a system which is adaptable to the various pressure supplies available in most laboratories. It consists of a supply line, strainer, constant-pressure regulator (diaphragm type), needle valve, and a solenoid valve connected with a pressure-balance chamber by a capillary restriction. Flexible hoses connect the chamber with the rotary clamp and a manostat which controls the pressure in the balance chamber by opening and closing the solenoid valve. A bleeder valve is also connected to the chamber for releasing the pressure during changing of the specimen. Proper preregulation by the constant-pressure valve makes it possible to keep the pressure under the specimen at ± 1 mm. mercury, securing a very uniform abrasion pressure and sample tension.

F. Special Edge-Abrasion Clamp

A special edge-abrasion clamp can be mounted in the rotary clamp instead of the rubber diaphragm. Warpwise, fillingwise, or bias strips, clamped as indicated in Figure 2, can be exposed either to a unidirectional reciprocating abrasion or to a multidirectional action by the reciprocating and simultaneous rotation of the rotary clamp. In selvedge and plain-fold abrasion, the machine is automatically stopped when the endpoint is reached by an electric contact between the contact pin in the abradant plate and the edge-abrasion clamp. When the folding plate is used, this plate forms the contact with the pin in the abradant plate when the edge of the specimen is rubbed off. This device is also suitable for the testing of yarns or monofilaments which can be wound under a certain tension around a flat plate with a round edge or a pin fitting to the edge-abrasion clamp.

G. Flat-Abrasion Table with Tension and Folding Device

This table is chiefly provided for flex-abrasion testing, as schematically illustrated in Figure 3. It can also be used, however, for the plane abrasion of fabric strips whereby the specimen can be stretched with a known force by a weight-lever mechanism.

The plane-parallel adjustment of abrasion table and abradant, which is very important for uniform test action, is accomplished here by a steel ball inserted between the flat-abrasion table and the mounting flange. On the sides of the table are adjusting plates which can be used for rigid plane-parallel mounting.

Flex abrasion of the specimen can be accomplished either by use of a folding and tension bar or by flexing the folded sample against itself. In the first case, the folding bar, which can have either sharp or rounded edges, is subjected to a controlled tensile load by the weight-lever system located in the bracket of the abrasion head. This device is also designed to make a contact to stop the machine when the endpoint is reached. In the second type of test, in which the folded sample is abraded against itself, the upper and lower plates are covered with a friction sheet (this may be regular abrasion paper) so that the folded specimen receives the proper rolling action from the reciprocating motion of the abrasion table. In all tests with the flat-abrasion table, the plane-parallel-guided abrasion head subjects the specimen to a controlled pressure.

H. Electric Devices

The electric devices mounted on the rear of the front panel serve to control the pneumatic specimen tension and to stop the machine automatically at the endpoint of a test. If the set pressure in the manostat is exceeded, the mercury contacts an adjustable platinum wire actuating a relay which closes the solenoid valve in the pressure line. The balloon height of the inflated specimen, which is a function of the elongation of the sample, can also be used to control the pressure. Thus the elongation under which the fabric is tested can be controlled and can be selected from a wide range. In this case the indicator installed on the lever mechanism of the abradant head makes contact to actuate the relay and the solenoid valve. Contact between the insulated abradant plate and the sample clamp mechanism or another part of the machine stops the motor by a manual reset relay which is actuated by a midget relay.

III. Control of the Abrasion Conditions

The foregoing description of the apparatus has also indicated, in general, how it can be used for measuring resistance to flat, edge, and flex abrasion. It is now intended to discuss the abrasion conditions mentioned in Part I.C. and to show how they are controlled in the various applications of the tester. Some results on the relative importance of these abrasion factors will indicate what has to be considered in the performance and evaluation of abrasion tests.

A. General Abrasion Conditions

It is obvious that the general conditions of temperature and humidity under which abrasion tests are conducted are of considerable significance. Normally, the standard conditions for testing textiles (70°F + 10 F and 65 ± 2 percent relative humidity) should be maintained unless special functional requirements (*e.g.*, use in extremely low temperatures) are indicated.

If the fabric is to be used in the presence of water or other liquid, it should be tested in a wet condition. Particular note should be taken of the possibilities afforded by this apparatus for the performance of both flat- and flex-abrasion tests on materials in a wet condition. Such tests, which are most important for all fibers with low wet-strengths, are difficult to carry out on most abrasion machines. In a flat abrasion test the specimen is clamped on the rotary head, then immersed in water or any other liquid. As the diaphragm is inflated, the central portion of the fabric surface is raised above the level of the liquid, a ring of the liquid being formed around the circumference. Thus, although the area of abrasion is not directly immersed during the test, it is kept wet by the wicking capacity of the fabric, further aided by a slight tendency of the liquid to splash onto the raised portion of the specimen by virtue of the test motion. The adhesive forces between the water and the fabric and abradant are another contributing factor in maintaining the fabric in a wet state during the test. In flex-abrasion experiments with the folding bar, the specimen strips are first immersed, then tested as in the dry state.

B. Nature of the Abradant

The nature of the abradant largely determines the character and degree of attrition, and is thus a major factor in the performance of any kind of abrasion tests. In the simulation of most service abrasion actions, the abradant must drag the fibers apart by friction rather than by a cutting action. For this reason, the use of mineral abrasives, which have a strong tendency towards cutting, has been objected to [3, 13, 24]. However, emery is still the most frequently used abradant in the testing of fabrics, largely because other materials—such as fabrics, metal screening, files, etc.—are either impractical or disadvantageous in some other respects [19].

It is logical that the grain size of an abradant should have a significant influence upon the wear pattern obtained in abrasion testing. When the dimensions of the emery grain are smaller than the thickness of the individual fibers, it can be expected that, instead of producing a snagging and cutting action, the abradant would have the effect of gradually breaking up the inherent cohesion of the fiber material. The latter condition exists for abradants of the fineness of Emery 0 or similar papers. It has been found [5, 12] that in actual wear innumerable small portions of the individual fiber are torn away. Cotton fibers, for example, break up into spicules about 2 or 3 microns wide and up to 40 and 50 microns in length. Rayons also show a splintering of the fiber as a result of actual wear and particularly in laundering. Similar patterns can be produced by the use of fine abrasion papers on the in-

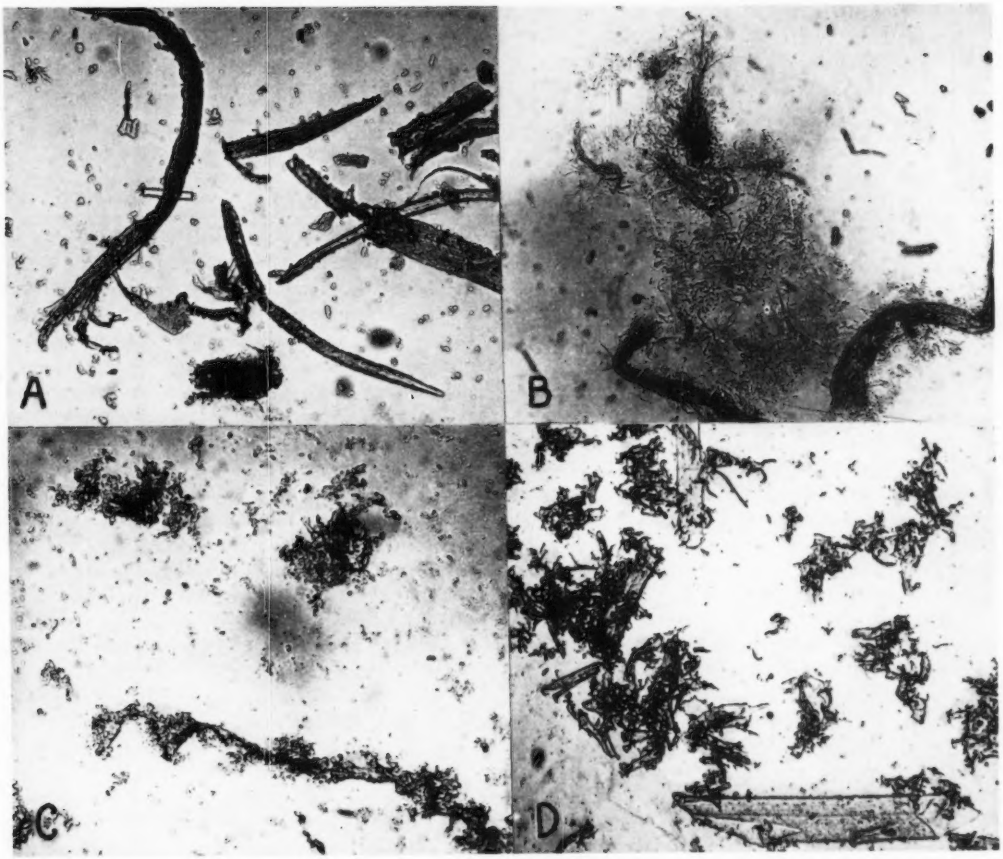

FIG. 6. *Photomicrographs of fiber debris produced by flat abrasion of various materials.* (a) *dry abrasion of tropical worsted fabric with Emery 0 abrasion paper;* (b) *wet abrasion of cotton fabric with water-resistant abrasion paper;* (c) *wet abrasion of standard viscose rayon fabric with water-resistant abrasion paper No. 500;* (d) *wet abrasion of highly oriented viscose rayon fabric with water-resistant abrasion paper No. 500.*

strument described in this report, as is demonstrated in the protomicrographs shown in Figures 6a to 6d, inclusive. In Figure 6a is shown the disintegration of wool fibers which occurred upon abrasion of a sample of tropical worsted fabric. Figures 6b, 6c, and 6d illustrate how the mechanical effect of laundering on cotton and rayon fibers can be reproduced by conducting a wet-abrasion test on the fabrics using a water-resistant abrasion paper such as silicon carbide No. 500.

Previous experimental studies [11] on abrasion papers have also indicated that the finest papers available are satisfactory as far as the character of attrition is concerned.

However, some of these abrasion papers are subject to a high deviation within themselves, and may also change considerably during the course of a test. Previous experiments have indicated [11, 19] that paper of sufficient uniformity can be secured so that deviation from abradant to abradant is not serious. With respect to the change of abradant with use, the calibration curve shown in Figure 7 has been established with this apparatus for Emery 0 paper used on two different types of worsted fabrics (flannel

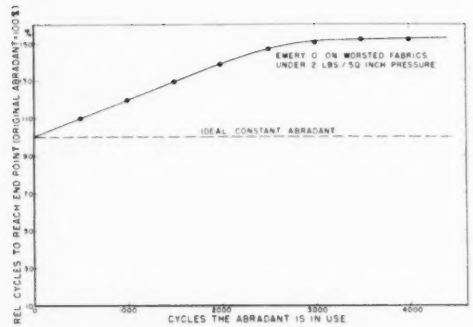
EMERY 0 ON WORSTED FABRICS
UNDER 2 LBS./SQ INCH PRESSURE
IDEAL CONSTANT ABRADANT
REL CYCLES TO REACH END POINT (ORIGINAL ABRADANT=100%)
CYCLES THE ABRADANT IS IN USE

FIG. 7. *Change of abrasion paper with use.*

and tropical worsted). This curve indicates the correction which must be applied in order to convert the results obtained to those which would be secured with an ideal constant abradant. In practical testing, however, such a correction has been found unnecessary because comparable materials produce a similar change of the abradant during testing, provided the abradant is changed after the evaluation of each specimen or at equal intervals.

For flat- and edge-abrasion testing with this instrument the abrasion papers Emery 0 and water-resistant silicon carbide No. 500 have shown satisfactory qualities and can be recommended. The construction of the flat-abrasion plate makes it possible to use a single abrasion sheet for several tests by slightly shifting the abrasion area after each test.

Use of constant abradants such as files [19] or laminated spaced plates similar to the Schiefer abradant [15] have not proved to be too suitable for this apparatus because of the high pressure and tension required to complete a test in a practical length of time. Also, the variation between samples of such abradants is larger than that between samples of a uniform abrasion paper.

In flex-abrasion testing with the folding bar, the bar serves not only as a means for maintaining the specimen in a folded condition and under tension, but also as an abradant—hence its surface and edges must be kept constant. In the evaluation of a test series consisting of more than 100,000 cycles performed with the same hardened steel bar, it was found that during this period the abrading characteristics of the bar (edge effect) did not change. (Note that in Table III there is no significant difference between the means of the vertical columns, which represent the sequence of test performance.)

However, the production of different bars with the same characteristics introduces the same problems which have been mentioned above. Calibration of the bars may help to overcome these difficulties and may permit calculation of results directly comparable with values obtained by different apparatuses.

C. Abrasion Pressure and Sample Tension

In the mechanics of solid materials the degree of abrasion is normally defined as the ratio of the quantity of abraded material to the quantity and pressure of the abrasion action [7]. The straight-line relationship which exists between these factors for most solid materials could also be found for a number of homogeneous textile fabrics [19]. With respect to textiles, however, it is rather difficult to determine the direct proportionality between the degree of abrasion and the normal pressure because, in testing as well as in actual wear, any change in abrasion pressure produces a simultaneous alteration in some other factors which also influence the degree of abrasion. But there can be no doubt that the normal pressure effective in the area of contact has an important influence on the degree of abrasion. Control of pressure conditions to obtain uniform abrasion entails not only regulation of the over-all load of the abradant on the sample, but also maintenance during the test of a uniformity of the normal pressure effective upon every location within the area of abrasion. Such control is extremely difficult due to the nature of textile fabrics, and this feature has not been accorded sufficient consideration in the construction of most abrasion instruments.

The new machine, with its combination of precisely guided abradant of controlled pressure and pneumatic sample clamping system, produces a uniform contact between fabric and abradant by the flattening of the balloon-shaped inflated sample. Due to the flexibility of most textile materials and the highly elastic extensibility of the diaphragm, it can be assumed for the forms used in the apparatus that the following relationship exists between the area of abrasion (A), the load of the abradant (L), and the air pressure under the diaphragm (p):

$$A = \frac{L \text{ (lbs.)}}{p \text{ (lbs. sq. in.)}} \qquad (1)$$

This equilibrium between abradant load and pneumatic pressure secures a uniform normal pressure in every location of the flattened contact (abrasion)

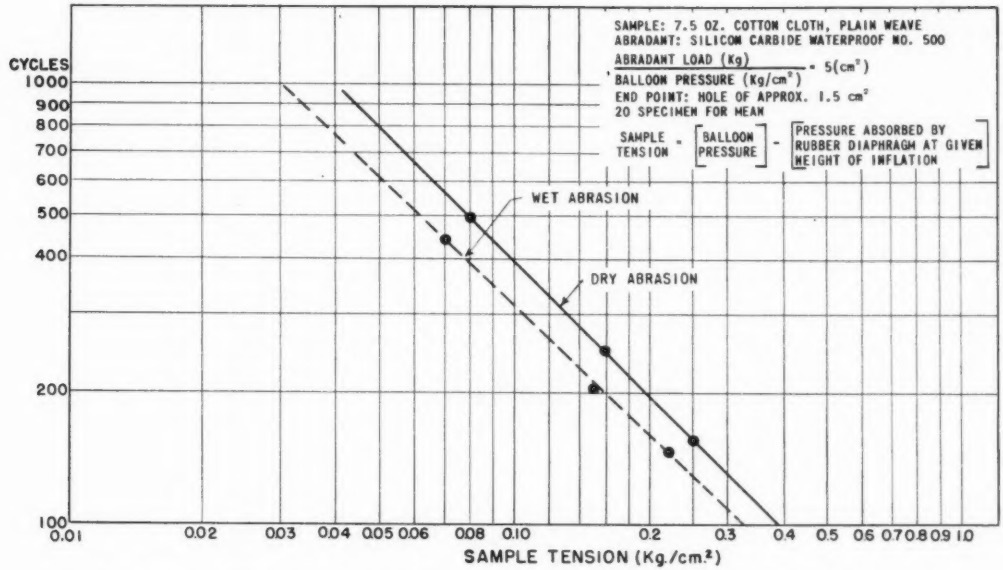
SAMPLE: 7.5 OZ. COTTON CLOTH, PLAIN WEAVE
ABRADANT: SILICON CARBIDE WATERPROOF NO. 500
ABRADANT LOAD (Kg) / BALLOON PRESSURE (Kg/cm²) = 5(cm²)
END POINT: HOLE OF APPROX. 1.5 cm²
20 SPECIMEN FOR MEAN
SAMPLE TENSION = [BALLOON PRESSURE] - [PRESSURE ABSORBED BY RUBBER DIAPHRAGM AT GIVEN HEIGHT OF INFLATION]
CYCLES
1000
900
800
700
600
500
400
200
100
WET ABRASION
DRY ABRASION
0.01 0.02 0.03 0.04 0.05 0.06 0.08 0.10 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
SAMPLE TENSION (Kg./cm²)

FIG. 8. *Relation between sample tension and resistance to flat abrasion of cotton fabric (dry and wet).*

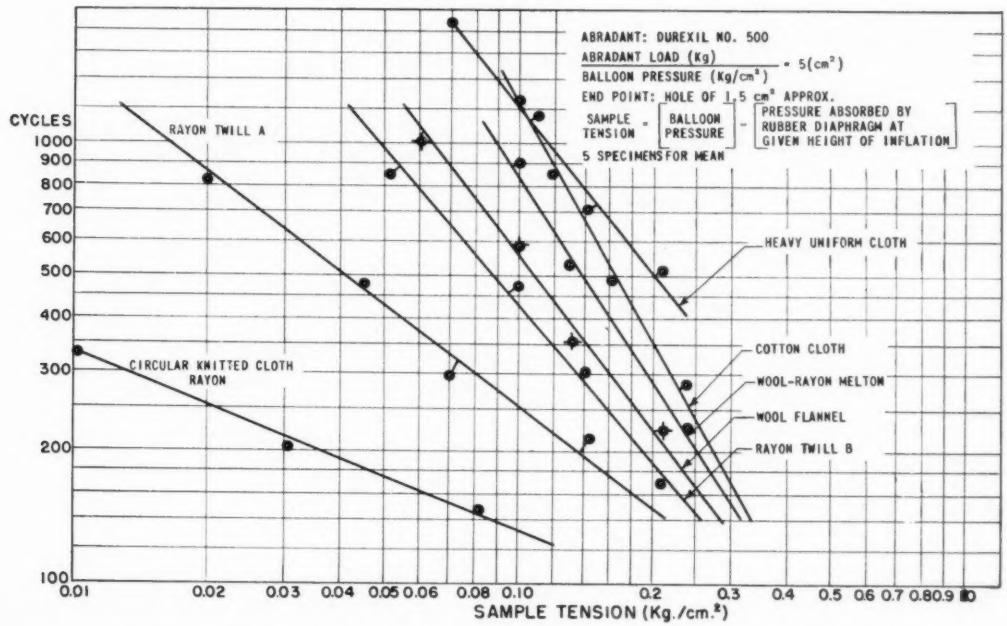

FIG. 9. *Relation between sample tension and resistance to flat abrasion of various fabrics.*

area, even if the sample is not of uniform thickness. The specific abrasion pressure (p) is equal to the air pressure, and independent of the abradant load (L). The latter, however, controls the area of abrasion. Since the air pressure under the diaphragm can be kept constant with an accuracy of ± 1 mm. of mercury, and regulated from 0 to 6 pounds per square inch, the abrasion pressure is controlled within a range which is approximately the same as that encountered in actual wear.

The influence of sample tension on mechanical disintegration by abrasion, folding, and flexing has been established for fibers, yarns, and fabrics [19, 22]. It has been found that the relation between resistance to abrasion or folding and sample tension is in principle a hyperbolic function with the general formula:

$$n = c \cdot p^a, \qquad (2)$$

where n is the resistance to abrasion, p the exterior tension applied to the sample, c a material constant chiefly dependent upon the inherent properties of the fiber and the total volume or weight per unit area of the sample, and a a form factor largely determined by the geometrical form of the fabric and yarn.

The relation between sample tension and resistance to flat abrasion is shown in Figures 8 and 9, in which are plotted test results obtained on this machine for a number of fabrics. These figures demonstrate the importance of precise control of sample tension throughout an entire test, and also show that resistance to abrasion under varying degrees of severity can only be indicated by tests conducted under different tensions. The sample tension shown in these figures is the pneumatic tension effective upon the specimen, which has been determined as the difference between the air pressure under the diaphragm (test pressure) and the portion of that pressure which is absorbed by the diaphragm at a given height of inflation (read from a calibrated curve for the rubber diaphragm).

The pneumatic tension causes two distinctive reactions in the specimen, each of which can be considered as a separate abrasion factor: (a) linear tensile stress effective in the direction of the threads, and (b) compression stress perpendicular to the plane of the specimen. The former is a hyperbolic function of the effective pressure p, the radius r of the clamped area, and the inflation h_1 of the specimen (balloon height). Equations (3) and (4), which have been derived for the bursting-strength test [16, 18], can be applied here for the evaluation of the linear tensile stresses which are effective during a flat-abrasion test with the pneumatically controlled sample clamp.

Linear tension in the direction of the threads:

$$K = p \cdot \frac{r^2 h_1^2}{4h_1} \text{ (lbs. in.)} \qquad (3)$$

Linear elongation of the specimen:

$$\delta = \left[\frac{(r^2 h_1^2)\pi\alpha}{r \cdot h_1 \cdot 360} - 1 \right] 100\% \qquad (4)$$

where

$$\tan \frac{\alpha}{2} = \frac{h_1}{r}$$

A schematic diagram of the inflated specimen shown in Figure 10 illustrates the conditions expressed in equations (1), (3), and (4).

The compression component mentioned under (b) is the normal pressure under which the abrasion is performed and is equal to the test pressure, as has been discussed earlier (equation (1)). This component, in reciprocal action with the frictional properties of specimen against abradant, determines the frictional forces and the energy of friction which is imposed upon the specimen during test. Further discussion of these actions and reactions and interpretation of the experimentally determined equation (2) must be reserved for a later study on the subject. They have been mentioned here only to indicate the influence of abrasion pressure and sample tension and to demonstrate how these two major abrasion factors can be controlled.

In flex-abrasion testing, pressure and tension control and uniform distribution of the stresses with the abrasion area are also secured with high accuracy, as has already been demonstrated in the description of the machine.

D. Character of the Abrasion Motion

The character of the motion between the sample and the abradant is another factor influencing the resistance to abrasion. Schiefer states [15] that uniform abrasion is dependent upon satisfaction of these two conditions: "(a) The instantaneous relative velocity between the abradant and the specimen is constant in magnitude and direction for every point of the abraded area, . . . and (b) the instan-

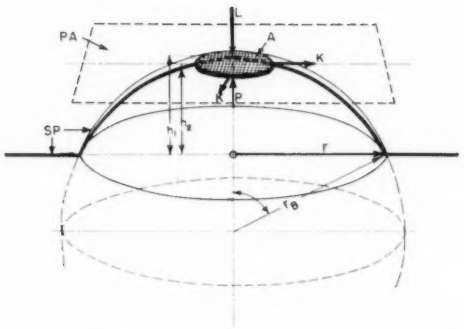

FIG. 10. *Distribution of abrasion pressure and fabric tension of inflated specimen.*

SP = Specimen
PA = Plane of the surface of abradant
r = Radius of the clamped area
h_1 = Deflection of the unflattened specimen
h_2 = Deflection of the flattened specimen
r_B = Radius of assumed spherical balloon
P = Air pressure inside the balloon
L = Load of abradant
A = Area of contact (abrasion)
K = Tensile stress in direction of thread (lbs. per 1-in. width)

taneous relative velocity between the abradant and the specimen at any point of this area is constant in magnitude but changes in direction relative to the specimen from instant to instant in a continuous and uniform manner." The first condition is approached by the apparatus described here in that the instantaneous velocity between the abradant and the specimen is the same in magnitude and direction for every point of the abraded area. However, this magnitude changes during a given cycle, as indicated in Figure 11. Thus, equal abrasive energy is exerted on each point of the specimen during each cycle. The condition of changing the direction of relative motion from instant to instant in a uniform manner is accomplished in a practical manner by cyclic rotation of the specimen in flat- and edge-abrasion tests, as is demonstrated in Figure 11.

If the specimen tension is two-dimensional as in the flat-abrasion with this apparatus, it has been determined that the influence of the relative direction of motion between abradant and specimen is not as significant as has been theoretically assumed. Table II, for example, demonstrates among other

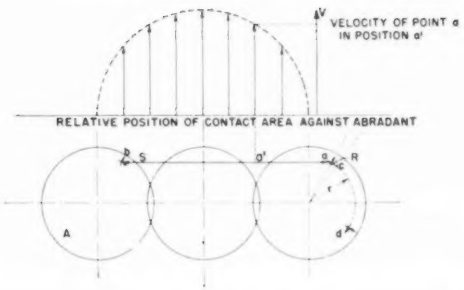

FIG. 11. *Motion between sample and abradant in flat-abrasion testing.*

A—Circular area of contact (abrasion) between specimen and abradant
a—Location of a given point on the abraded surface of the specimen at the beginning of a stroke
b—Same as a at the end of a single stroke
c—Same as a at the end of a double stroke
d—Same as a after 25 double strokes
r—Distance of this point from center of contact area
S—Magnitude and direction of the longitudinal reciprocating displacement
R—Magnitude and direction of rotational displacement:

$$R = \frac{2\pi r}{100},$$

where $0 \leq r \leq \sqrt{\frac{L}{p \cdot \pi}}$, L = abradant load, and p = pneumatic pressure.

Under normal operating conditions of the machine, the ratio between the maximum rotational displacement (R_{max}) and the longitudinal reciprocating displacement (S) is less than .013.

v—Velocity of the reciprocating motion at given positions:

$$v = m \cdot \omega(\sin \alpha + (\lambda/2) \sin 2\alpha)$$
$$v_{max} = m \cdot \omega \sqrt{1 + \lambda^2}$$
$$v_{mean} = 0.637 m \cdot \omega,$$

where $m = \frac{S}{2}$ (crank radius), ω = angular velocity of the crank, α = crank angle, and λ = ratio of crank radius to length of stroke arm.

things that under a 4-lbs.-per-sq.-in. pressure the sateen No. 111 abraded filling (face up) reached the endpoint at 731.8 cycles when abraded from every direction, at 729.2 cycles when abraded parallel to the warp yarns, and at 747.3 cycles when abraded parallel to the filling yarns. These results indicate that in a state of tension equilibrium in warp and

filling directions the production of a hole by attrition is largely determined by the intrinsic resistance of the fiber material to the specific abradant and by the thickness of the layers which must be rubbed through. Under such conditions the direction of the action is of minor influence. If the distribution of the tension, however, is not uniform or if the fabric consists of layers which are under different tensions, then the direction becomes a major factor of the resistance. Such conditions exist frequently in practical wear and they are the major cause for the superiority of certain fabric constructions for specific purposes. Later in this paper the effect of unidirectional tension and abrasion motion will be discussed in connection with accelerated combat-service test results. In summary, cognizance should be had that the simulation of service action often calls for unidirectional abrasion and unidirectional specimen stress. Therefore, a tester should be capable of reproducing this type of action as well as multidirectional abrasion of uniform intensity over the abraded area.

E. Removal of Lint and Other Debris

The last factor considered in the design of this machine is that of removal of lint or debris during conduct of the test. In flat-abrasion testing most of the abraded debris is removed from the contact area by virtue of the balloon shape in which the fabric is held, so that the test action cannot be seriously affected by this residue. It was found in a quantitative test that manual removal of the lint during the abrasion can have a slight effect upon the relative precision and the average number of cycles required to reach the endpoint. In one test series, for example, the coefficient of variation of cycles for each endpoint has been decreased from 10.3% to 8.1% by removing the loose matted fibers at definite intervals, but comparative tests have also indicated that this does not significantly change the results obtained. Thus it is possible to perform experiments on this apparatus without interruption from the start of the test until the machine is automatically stopped as the endpoint is reached.

In edge-abrasion tests with the special clamp described earlier in this report the removal of debris is no problem since the rubbed-off fibers can cause practically no disturbance in the area of abrasion due to the shape of the specimen and the character of the motion.

In flex-abrasion testing with the folding bar it was found that most of the lint was removed from the area of flexing and abrasion. To a certain extent, pieces of fiber debris mat together between the specimen and the bar on the narrow front side of the folding bar. However, this condition does not change either the diameter of the bending action or the effect of the edge of the bar; hence, it has no significant influence upon the number of cycles required to rupture the specimen.

IV. Macro- and Micro-Wear Patterns and Their Connection with the New Wear Tester

It has already been mentioned in this report that an abrasion machine need not necessarily reproduce service wear actions in their entire complexity. But there is no doubt that the wear patterns produced by laboratory abrasion must be comparable to those obtained in corresponding service wear. In the comparison and interpretation of wear patterns certain principles should be observed which hitherto have not been given sufficient consideration.

A distinction should be made between a macro-wear and a micro-wear pattern. The macro-wear pattern is identical with the surface appearance of damages caused by plane abrasion, projection abrasion, flex abrasion, or abrasion of folded or stitched edges. These can generally be classified into wear areas and holes in wear. The type of pattern is largely determined by the surface character of the abrasive and the size of the contact area, by the motion between abrasive and sample, and by the geometric form of the weave and yarn structure. The micro-wear pattern can be described as the type of break-up of the individual fibers which is effected by the reciprocal action of all three cohesive forces (see Part **I**.*B*. and Part **III**.*B*.). It is possible that the same macro-wear pattern is formed by an action which cuts the fibers or produces a combined snagging, tearing, and unraveling effect upon the yarns such as is formed by gradual attrition. Since the latter is in most instances of practical wear the most important type of mechanical disintegration, it is necessary that in abrasion tests not only the macro-wear pattern, but the micro-wear pattern as well, correlate with those obtained in service wear. The importance of the micro-wear pattern, not only from a testing viewpoint but also for the engineering of wear-resistant fibers and fabrics, becomes more in-

FIG. 12. *Photomicrograph of fiber debris produced by flex abrasion of cotton sateen.*

telligible when we consider that wear resistance must have an inverse relationship to the fragment size of the rubbed-off fibers [25]. (The influence of the abradant upon the fragment size has already been discussed in Part **III**.*B*.) But besides the abrasive, which in actual wear changes continuously and in a very wide range, other factors—such as the geometrical form of the weave, yarns, and fibers and the inherent cohesion of the fiber material itself—also determine the size of debris which is formed. These factors, for example, are the major cause for the superior durability of coarser-denier fiber in staple rayon fabrics of the same construction and with the same inherent properties of the fiber material [20]. In fabrics made of fine-denier fibers the cohesion between abrasive and fiber frequently produces a rupture of the entire fiber cross section, whereas when coarser fibers are used only a portion of them is torn out and the average size of the fiber fragments is smaller. These actions and reactions as indicated by the micro-wear pattern can be summarized in terms of mechanics as follows: The amount of work required to abrade a fabric is proportional to the surface area of the fiber fragments. It is recognized, however, that only a relatively small amount of the energy expended in abrasive action (frictional work) is actually effective in mechanically disintegrating the fibers; most of it is absorbed by a visco-elastic deformation of the fiber, or by a displacement of the fiber within the yarn or fabric structure.

Micro-wear patterns produced by dry and wet flat abrasion on the new apparatus have already been discussed in connection with the effect of abradants and are shown in Figures 6a to 6d inclusive. The micro-wear pattern shown in Figure 12 is typical for a cotton fabric subjected to flex abrasion with the folding bar. The similarity of these patterns to those obtained by actual wear, as described in previous papers [5, 12] and also in this report, is evident.

Area of abrasion and endpoint are two factors in abrasion testing which must also be considered together with the macro-wear pattern. The concentration of abrasion action within a small area does not influence the simulation of service wear as long as sample tension and abrasion pressure are comparable to those effective in service. These conditions exist for all three types of abrasion produced on this apparatus. A relatively small abrasion area, however, ensures much more accuracy in the attempt to evaluate visually the progress of abrasion [3] and to obtain a controlled endpoint which corresponds to a hole in wear. These conditions are met both in flat abrasion with the pneumatically controlled rotary clamp and in flex abrasion with the folding bar. Figure 13 is a macrophotograph of a flat-abraded specimen of tropical worsted at endpoint, and Figure 14, of a sample of a cotton sateen subjected to flex abrasion. The picture of the latter was taken shortly before the endpoint was reached by rupture. Both are typical of the macro-wear patterns and endpoints obtained on the apparatus and are similar to known [10, 23] macro-wear patterns of fabrics after service usage.

Knit goods have long presented a difficult problem with respect to the development of an abrasion test which results in a uniform wear pattern capable of quantitative evaluation. Figure 15 illustrates that this condition can be met with the new instrument even for a loose-knitted construction.

V. Accuracy and Applicability of the Machine

The accuracy of the new machine, as of any other abrasion and wear tester, is determined by the fol-

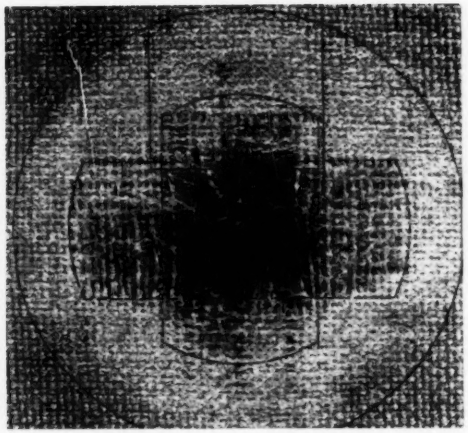

FIG. 13. *Dry-abraded specimen of tropical worsted at endpoint. Cross-shaped area of abrasion is due to the division of the radial tension between warp and filling threads.*

lowing conditions: (*a*) establishment of an endpoint which is independent of individual judgment and can be quantitatively defined; (*b*) obtaining of test results whose deviation due to the machine is insignificant as compared to the deviation within the sample itself; (*c*) capability of measuring the quantity of abrasion action and the quantity of abraded material; (*d*) correlation of the results with corresponding reactions from service wear.

Conditions (*a*), (*b*), and (*c*) determine the precision of the tester and are the prerequisites for correlation between wear data and laboratory test results. (*d*) depends upon the ability of the laboratory tests to reproduce the specific reactions to which a fabric is subject in wear, and upon the employment of a quality index or ranking system which is based upon a properly weighted combination of the separately measured reactions.

A. Precision of the Machine

Condition (*a*) is met in flex abrasion with the folding bar by rupture of the specimen strip which has a given cross-sectional area. In edge abrasion the endpoint is reached when that portion of the specimen which is above the clamp is completely worn away. The quantity of this abrasion is determined by the type of clamping (Figure 2), the unit weight, and the width of the specimen.

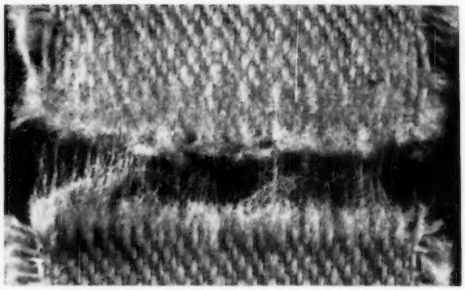

FIG. 14. *Flex-abraded specimen of cotton sateen shortly before rupture.*

Requirement (*b*) is also sufficiently satisfied in flex and edge abrasion. Here, variation in the number of cycles required to reach the endpoint is in the same range as that determined for the breaking strength of similar fabrics [6] or other fabric uniformity measurements. It can therefore be assumed that the variations (shown, for example, in Table III) are largely the result of the deviation within the sample itself.

The quantity of abrasion action for flex and edge abrasion is proportional to the number of cycles. The quantity of destruction is determined by the disintegrated cross section of the specimen. This can be expressed either on a weight basis (as, for example, in the grex system) or in terms of the cross section of the solid material. The ratio of these two quantities defines the specific abrasion

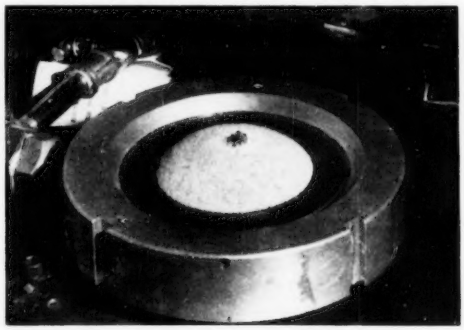

FIG. 15. *Flat-abraded knitted fabric at endpoint.*

resistance of the sample as it has been already mentioned in Part I.D. Thus, requirement (*c*) is met in flex and edge abrasion with the new apparatus.

In flat abrasion the endpoint is reached when electrical contact is made between the diaphragm and the abradant plate. This is the case when all the fibers in the center of the abrasion area are worn off (Figures 4, 13, and 15). Due to the precise control of the contact between abradant and specimen the holes produced are highly uniform in shape and size, as can be seen in Figure 16. In comparative testing the size of the hole can serve as a parameter for the quantity of abrasion. The number of cycles required to reach the endpoint is a measure of the quantity of abrasion action. But the quantity of abrasion can also be determined in terms of weight of the abraded material. Instead of weighing the specimen before and after abrasion, the following method has been found to be more accurate: From each abraded specimen two one-sq.-in. cutouts are made with a die—one from the abraded portion and the other from an unabraded part of the same specimen. The means of these small abraded and unabraded samples and their standard deviations are then calculated. The difference between the two means represents the weight of the abraded material, and comparison of the standard deviations gives an indication of the variations due to the machine and due to the unevenness of the fabric. Table I demonstrates such an evaluation, where each series consisted of 28 abraded specimens. (The cutouts of the abraded portion of Series 1 are shown in Figure 16.)

TABLE I. DEVIATION OF FLAT-ABRASION RESULTS

		Series 1	Series 2
Average cycles to endpoint		500.6	435.2
Coefficient of variation of cycles (%)		10.3	8.1
Weight of 1 sq. in. (grams)	$\bar{X}_1$	0.1902	0.1898
Unabraded section	σ_1	0.0031	0.0031
Weight of 1 sq. in. (grams)	$\bar{X}_2$	0.1677	0.1724
Abraded section	σ_2	0.0037	0.0034
Weight of abraded material	$(\bar{X}_1 - \bar{X}_2)$	0.0225	0.0174
Standard error of difference	$\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$	0.0009	0.0009

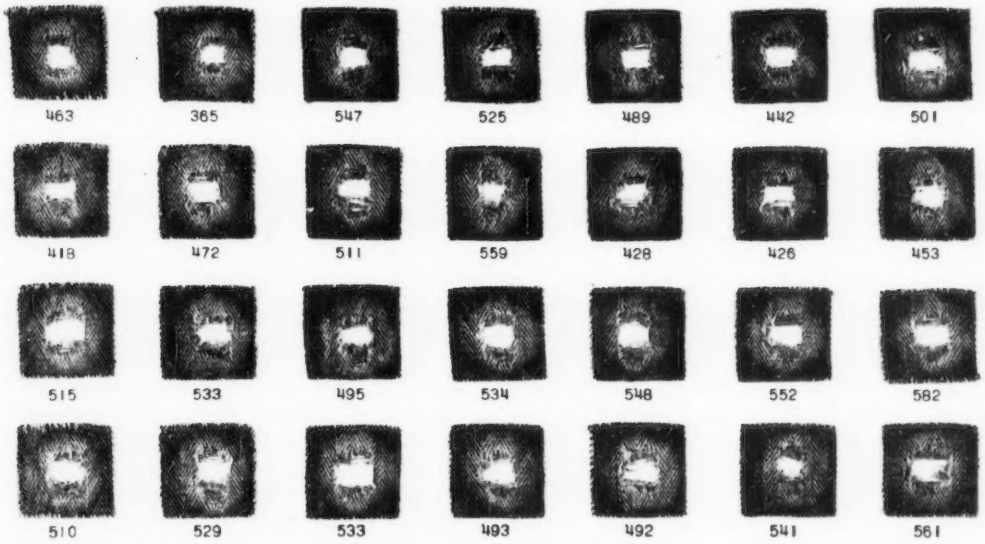

FIG. 16. *Uniformity of endpoint obtained in flat abrasion.*

TABLE II. FLAT-ABRASION DATA SHOWING ACCURACY OF MACHINE AND INFLUENCE OF TEST CONDITIONS

Sample	Test conditions: Position of the sample*	Test conditions: Abrasion direction	Test conditions: Diagonegm pressure	Cycles to reach endpoint: $\bar{X}$	Cycles to reach endpoint: σ	Cycles to reach endpoint: $V(\%)$	Weights of 1-sq.-inch areas cut out from each specimen (grams): Unabraded: $\bar{X}_f$	Unabraded: σ_f	Unabraded: $V_f(\%)$	Abraded: $\bar{X}_a$	Abraded: σ_a	Abraded: $V_a(\%)$	Weight of abraded material† (grams)	Cycles to Weight $\left(\frac{c}{G}\right)$	Coefficient of friction** $\mu_S T$	Coefficient of friction** μ_D	Frictional work Abraded material‡ (kgs. s. static dynamic ($\mu_S T$) (μ_D)
Sateen (#111)	Face	Multidirectional	2 lbs. sq. in.	3122.1	431.0	13.8	.2352	.0082	3.5	.1821	.0056	3.0	.0531 ± .0031	5.88×10^3			
			4 lbs. sq. in.	731.8	82.8	11.3	.2294	.0075	3.3	.1879	.0083	4.4	.0415 ± .0035	1.76×10^4	.77	.76	470 462
			5½ lbs. sq. in.	388.7	34.6	8.9	.2338	.0057	2.5	.1927	.0073	3.8	.0411 ± .0029	0.95×10^4			
	Back	Multidirectional	4 lbs. sq. in.	708.6	77.0	10.9	.2333	.0037	1.6	.1896	.0046	2.4	.0530 ± .0019	1.44×10^4			
		Parallel to warp	4 lbs. sq. in.	729.2	55.1	7.6	.2363	.0061	2.6	.1911	.0048	2.5	.0452 ± .0024	1.61×10^4			
	Face	Parallel to filling	4 lbs. sq. in.	747.3	96.9	13.0	.2400	.0047	2.0	.1926	.0049	2.5	.0474 ± .0021	1.57×10^4			
Sateen (#117)	Face	Multidirectional	4 lbs. sq. in.	787.8	79.8	10.1	.2283	.0047	2.1	.1885	.0037	2.0	.0398 ± .0019	1.98×10^4	.70	.64	479 438
	Back	Multidirectional	4 lbs. sq. in.	947.1	82.0	8.7	.2237	.0056	2.5	.1762	.0035	2.0	.0475 ± .0021	1.99×10^4			
HBT (#100)	Face	Multidirectional	4 lbs. sq. in.	826.7	113.8	13.8	.2276	.0029	1.3	.1845	.0038	2.1	.0431 ± .0015	1.91×10^4	.68	.63	448 414
HBT-M (#103)	Face	Multidirectional	4 lbs. sq. in.	618.3	54.0	8.7	.2244	.0059	2.6	.1859	.0050	2.7	.0385 ± .0023	1.61×10^4	.78	.75	432 416
Plain (#104)	Face	Multidirectional	4 lbs. sq. in.	656.7	59.8	9.1	.2077	.0042	2.0	.1679	.0033	1.9	.0398 ± .0017	1.65×10^4	.73	.70	416 398
Oxford (#107)	Face	Multidirectional	4 lbs. sq. in.	574.8	55.2	9.6	.2193	.0069	3.1	.1787	.0045	2.5	.0406 ± .0026	1.42×10^4	.78	.77	386 381
Sateen (#114)	Face	Multidirectional	4 lbs. sq. in.	711.6	46.4	6.5	.2349	.0015	0.6	.1922	.0030	1.5	.0377 ± .0011	1.89×10^4	.76	.70	495 456

* "Position of the sample" refers to the surface of the fabric which is in contact with the abradant. ("Face" is the surface worn outside. In these sateens, the filling yarns were flush on the outside surface.)

† Standard error of weight of abraded material = $\sqrt{\frac{\sigma_f^2 + \sigma_a^2}{n}}$.

** Coefficient of friction determined by Deeby Friction Meter.

‡ Frictional work = $\frac{\text{Cycles} \times \text{stroke length} \times 2 \times \text{abradant load} \times \text{coefficient of friction}}{\text{Weight of abraded material}}$.

The coefficient of variation of the cycles required to reach the endpoint in flat-abrasion tests (see Tables I and II) lies within the same range as that discussed above in connection with flex-abrasion tests. But an even better indication of the precision of the machine is the insignificance of the difference between the deviations of the unabraded and abraded samples, as shown in Table I. If this difference were high, it would indicate that much of the variation noted in the abraded samples was attributable to the machine.

Thus, considerations (*a*), (*b*), and (*c*) are also met in flat-abrasion testing with the new machine. The resistance to flat abrasion can be expressed as the ratio of the quantity of abrasion action (average cycles to endpoint) to the quantity (weight) of abraded material. It is remarkable that this can be obtained independently of other test methods—such as tensile or bursting strength, or thickness measurements—by the production of a defined degree of damage which is similar to an actual hole produced in wear.

In some fundamental studies it may be desired to determine the quantity of abrasion action in terms of the frictional work expended during a test. The design of the apparatus makes it possible for an electric strain gage to be mounted in one of the bearings of the abrasion head. This can be used for continuous recording of the frictional force between sample and abradant. For an approximate evaluation, however, it is also possible to determine the coefficient of kinetic friction between sample and abradant in a separate test by means of a friction meter [4], since it has been found that in repeated actions the coefficient soon reaches a constant value. The product of this value and the load of the abradant determines the frictional force effective during the test. The frictional work is obtained by multiplying this value by the distance of the reciprocating abrasion action and the number of cycles. Examples of such an evaluation are shown in Table II for various fabrics tested under different conditions.

B. Correlation with Service Wear and Determination of a Laboratory Wear Index

An extensive presentation and interpretation of results concerning correlation with wear tests must be reserved for another paper. However, the data shown in Tables II to V inclusive and Figure 17 will give a preliminary indication of the extent to which this tester may help to solve the much discussed and frequently misunderstood problem of predicting wear resistance on the basis of laboratory data. The fabrics concerned were evaluated on a broad basis on the Quartermaster Board Combat Course at Camp Lee, Virginia, in addition to being subjected to flat and flex abrasion by the new apparatus. In the combat-course tests there was a wide variability in the wear scores of garments made from the same fabric, which tended to obscure the existence of significant differences among the materials. However, a careful statistical evaluation revealed that the 8 fabrics can be significantly ranked in the order of greatest resistance to wear as follows:

1. No. 114—Sateen, 10.6 ounce, with 25 percent nylon in the filling; and No. 117—Sateen, 10.1 ounce, with 50 percent nylon in the filling.
2. Nos. 111 and 112—Sateen, 10.2 ounce and 10.5 ounce, respectively, 100 percent cotton.
3. No. 103—HBT Modified, 10.1 ounce; No. 107—Oxford, 9.7 ounce; and No. 100—HBT, 9.9 ounce (the latter somewhat poorer than Nos. 103 and 107).
4. No. 104—Plain weave, 9.2 ounce.

Since yarn count and twist were the same for these experimental fabrics (all of the cotton constructions were made of approximately the same yarns), the difference in wear resistance can be attributed to two major factors—namely, (1) the use of nylon-blended filling yarns, ensuring an inherently higher resistance, and (2) the geometrical form of the weave. The slight difference in weight among the fabrics is a minor factor in accounting for the difference in wear resistance, as is apparent when the laboratory data are related on a unit-weight basis.

Table II presents the data obtained by flat-abrasion tests, in which variations were made in the surface of the sample abraded, the abrasion direction, and the diaphragm pressure. As has been noted previously, this table demonstrates the quantitative method for evaluating flat-abrasion resistance and also indicates the accuracy obtainable in this application of the tester.

Table III shows the individual data obtained in flex-abrasion tests of warp strips, with the folding bar in contact with the fabric face. These figures demonstrate the consistency of results and also indicate the constancy of the folding bar, as has been discussed earlier in this report. Flex-abrasion tests were also performed in the directions of the warp.

TABLE III. FLEX ABRASION DATA SHOWING RELATIVE PRECISION OF MACHINE

Sample No.	Weave	Ends per Inch	Number of cycles (double strokes) to rupture: Specimen 1	2	3	4	5	6	7	8	9	10	$\bar{X}$	σ	V (%)
100	HBT	81.3	862	967	924	742	889	937	949	905	995	872	904	70.7	7.8
103	HBT Mod.	82.1	997	909	944	984	1050	889	966	948	965	1147	980	73.9	7.5
104	Plain	81.5	758	945	735	849	894	1035	796	968	1020	1066	907	118.9	13.1
107	Oxford	84.9	1124	922	756	899	1100	1120	760	978	950	1015	962	134.3	14.0
111	Sateen-C	84.1	936	1212	1006	1022	1234	1204	1216	1342	969	990	1113	142.5	12.8
112	Sateen-C	85.5	1010	1040	1022	1232	1199	1071	1200	1347	1277	1370	1177	134.2	11.4
114	Sateen-25N	84.6	1626	1758	1796	1727	1569	1317	1612	1787	1657	1730	1658	142.6	8.6
117	Sateen-50N	84.0	1922	2088	1930	1727	2135	1799	1663	1687	1883	1957	1879	160.8	8.6
		Σ	9235	9841	9113	9182	10070	9372	9162	9962	9716	10147	9580		
		σ	447	447	460	385	415	288	345	351	363	388			

Test conditions:
Folding bar ($\frac{1}{16}$ by $\frac{3}{4}$ in. hardened tool steel)
4-lbs. pressure load on abrasion head
4-lbs. tensile load on folding bar
$\frac{1}{4}$-inch stroke length
120 double strokes per minute
Specimen: Warpwise strips, 1-inch wide
Sequence of test performance: Specimen # 1 of each sample tested in order shown in table, followed by specimen # 2 of each sample in same order, etc.

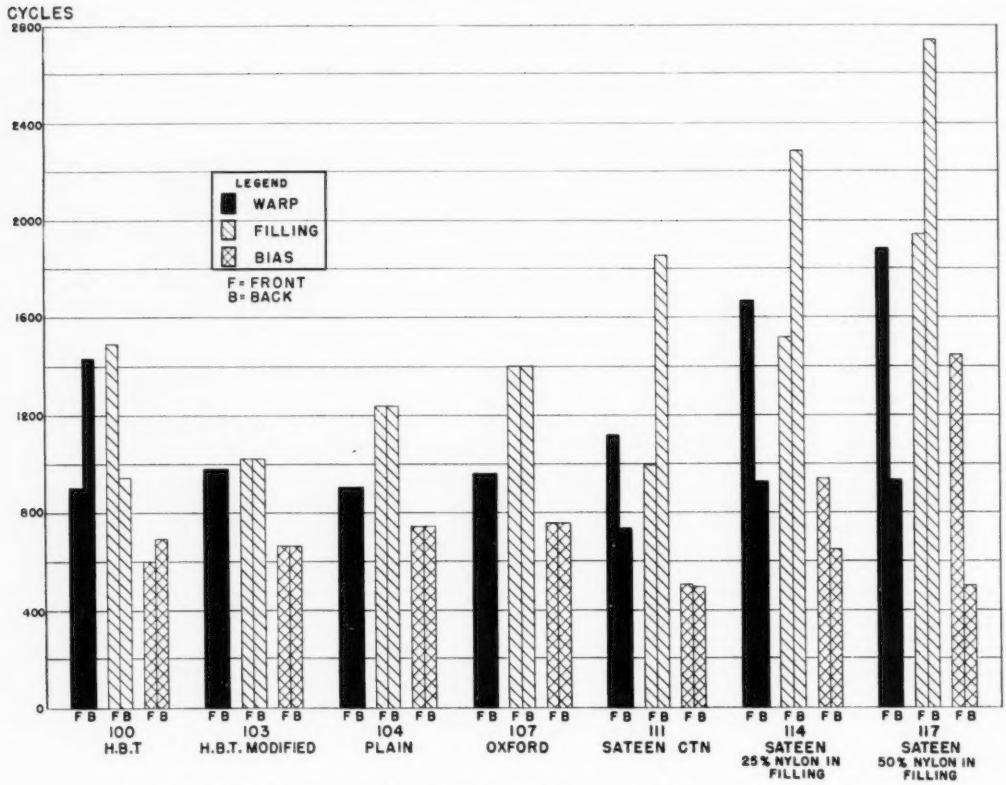

FIG. 17. *Resistance to flex abrasion of fabrics tested in different directions.*

filling, and bias both on the face and back of the fabric, and the results obtained are shown graphically in Figure 17.

The development of a quality index on the basis of a weighted consideration of the various laboratory wear components involves the conversion of absolute to relative values. An accurate and simple method of accomplishing this is to express the absolute data as a percentage of the average value of each property included in the series. The weighted combination itself must be based upon the selection of test actions corresponding to those predominant on the combat course and upon the application of the wear composition deducted by salvage studies. In accordance with the results of previous investigations [10, 23] and the general composition of wear presented in Part I.1. of this report, the following two formulae have been used in the calculation of quality indices:

Formula I	
(Column q in Table IV)	.50 flex abrasion, warpwise, face of fabric in contact with folding bar
	.20 flat abrasion, multidirectional (cycles per unit-abraded-area)
	.30 tear resistance (average warp and filling).
Formula II	
(Column r in Table IV)	.40 flex abrasion, warpwise
	.20 flex abrasion, over-all
	.20 flat abrasion, multidirectional
	.20 tear resistance

The relative laboratory data obtained as a result of these evaluations are shown in Table IV together with the quality indices (based on the two formulae) and the combat-course rankings. The relative data

TABLE IV. RELATIVE FLAT- AND FLEX-ABRASION DATA AND WEIGHTED LABORATORY QUALITY INDICES COMPARED TO COMBAT-COURSE RANKING

	Flat abrasion (multidirectional) Face* of fabric in contact with abradant					Flex abrasion (unidirectional) Folding bar in contact with face of fabric								Over-all	Over-all abrasion	Tear resistance	Laboratory quality index		Combat-course ranking
Fabric	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*	*r*	*s*
100	118	109	108	98	97	76	116	77	90	150	57	108	105	97.5	103	81	81.7	85.5	4
103	88	92	94	98	99	82	79	85	82	102	62	104	89	85.5	90	78	84.2	85.3	3
104	93	94	87	94	87	76	96	95	89	95	76	117	96	92.5	90	65	74.9	79.3	5
107	82	81	79	90	87	80	109	96	95	100	86	118	101	98	88.5	80	81.4	85.0	3
111	105	102	102	109	111	93	77	66	79	76	114	80	90	84.5	93	127	106.8	101.7	2
112						98	54	77	76	83	98	91	91	83.5		119		101.9	2
114	102	108	115	108	114	138	118	120	125	96	139	103	113	119	117	117	126.9	125.2	1
117	112	114	115	103	105	157	151	184	164	98	168	79	115	139.5	127	133	129.4	138.3	1
Av.	100	100	100	100	100	100	100	100		100	100	100		100.0		100			

* Face is that surface of the fabric which is worn outside.

a—Cycles to reach endpoint
b—Cycles per unit-abraded-weight
c—Cycles per unit-abraded-area
d—Frictional work per unit-abraded-weight
e—Frictional work per unit-abraded-area
f and *j*—Cycles to rupture (warp direction)
g and *k*—Cycles to rupture (filling direction)
h and *l*—Cycles to rupture (45° bias)
i—Average of *f*, *g* and *h*
m—Average of *j*, *k* and *l*
n—Average of *i* and *m*
o—Average of *n* and *c*
p—Average of warp and filling tear (Elmendorf tearing-strength test)

TABLE V. RANK CORRELATION BETWEEN COMBAT COURSE EVALUATION AND LABORATORY TEST DATA

Combat course ranking versus:		Columns in Table IV	Spearman's Rank Correlation Coefficient
Multidirectional flat abrasion			
Uniform two-dimensional tension—face of fabric in contact with abradant	Cycles to reach endpoint	*a*	0.232
	Cycles per unit abraded area	*c*	0.732
	Frictional work per unit abraded area	*e*	0.822
Unidirectional flex abrasion			
Folding bar in contact with fabric face	Warp direction	*f*	0.930
	Filling direction	*g*	0.582
	Bias	*h*	0.618
Folding bar in contact with fabric back	Warp direction	*j*	0.572
	Filling direction	*k*	0.488
	Bias	*l*	0.036
Over-all flex abrasion		*n*	0.700
Over-all flat and flex abrasion		*o*	0.834
Tear resistance		*p*	0.870
Laboratory quality index		*q*	0.999
		r	0.940

of the individual properties and indices, compared with the combat-course results by Spearman's Rank Correlation Coefficient,* are shown in Table V.

On the basis of these results the following observations may be made:

* Spearman's Rank Correlation Coefficient, r_S, is expressed by the formula:

$$r_S = 1 - \frac{6\Sigma d^2}{n(n^2 - 1)},$$

where d is the difference in rank between combat-course and laboratory data of test samples, and n is the number of ranks. An r_S value of 0 indicates no correlation; an r_S value of 1 indicates perfect correlation.

A weighted combination of the resistance to specific actions determined separately on the new multipurpose abrasion tester, supplemented by laboratory data on tear resistance, provides an excellent correlation with the combat-course results.

The isolated test action with the highest statistical correlation with the combat-course results has been found to be flex abrasion in the warp direction with the face of the fabric in contact with the folding bar. This action involves both abrasion and flexing in the warp direction, with the warp threads subjected to both tensile stress and compression, and the filling

threads to compression only. The major wear factor in combat-course testing is a combination of this abrasion action and tearing. Due to the geometry of the fabrics the resistance to flex abrasion varies in a rather wide range, depending upon the distribution of the tensile and compression stresses effective upon the two sets of yarns. In some weaves—such as that of the sateens evaluated in these tests—the yarns which are only compressed serve as a cushion, protecting those yarns which are subjected to tensile stress. The results shown in Figure 17 demonstrate the advantage that can be taken of this phenomenon in selecting fabrics with maximum resistance to this type of action.

In flat-abrasion testing, neither the surface of the fabric abraded nor the direction of abrasion nor the weave has much influence upon the results obtained when the tension is evenly distributed on warp and filling threads of the sample. It is evident that under such conditions resistance is largely influenced by the inherent strength of the fiber material, the surface and form factors of the individual fiber, and the unit weight of the fabrics. However, if the resistance is expressed quantitatively as the ratio between cycles per unit abraded area,* or even better, as frictional work per unit abraded area, some differences in weave do become apparent. The sateens are thus seen to be slightly superior to the twills, and the twills to the plain and Oxford weaves used in these tests. (See Table II and also note correlation of these values with combat-course results in Table V.)

These results have indicated how the new tester can be applied as a versatile instrument for the quantitative evaluation of wear factors. The data presented also demonstrate that a high correlation between laboratory test results and accelerated service wear can be secured. Further experimentation with the apparatus will help to analyze the complex property of wear resistance of textiles more accurately than has been possible by previous laboratory methods or by service tests alone.

Acknowledgment

The author wishes to acknowledge with gratitude the close cooperation of Mr. Frederick Balas in all of this work. The painstaking efforts of Miss Marie LaBadessa in the preparation of the samples and her assistance in the performance of the tests are also appreciated. In addition, the author is indebted to Mr. Seaman J. Tanenhaus for supplying considerable information on the results of combat-course tests and their interpretation.

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* The number of cycles per unit abraded area is obtained by multiplying the cycles required to abrade a unit weight of the material (as shown in Table II) by the unit weight of the fabric (oz. per sq. yd.).

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A New Method of Evaluation of the Crystallite Orientation of Cellulose Fibers from X-Ray Data—Appendix

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The following data pertaining to the paper by this author, which appeared in the June, 1949, issue of TEXTILE RESEARCH JOURNAL, page 330, was received too late for inclusion in the June issue.—Editor.

Mathematical Derivation of Equation (1): $\cos\theta = \sin\alpha \sin\beta \sin\gamma + \cos\beta \cos\gamma$ *

Let OA = unity, $OC = \cos\beta$, $AC = \sin\beta$, $BC = \cos\beta \tan\gamma$, and $OB = \dfrac{\cos\beta}{\cos\gamma}$.

From the geometry of the figure,* considering the triangle ACB,

$$AB^2 = AC^2 + BC^2 - 2AC\,BC\cos\left(\frac{\pi}{2} - \alpha\right)$$
$$= \sin^2\beta + \cos^2\beta\tan^2\gamma - 2\sin\beta\cos\beta\tan\gamma\sin\alpha.$$

Also, considering the triangle AOB,

$$AB^2 = OA^2 + OB^2 - 2OA\,OB\cos\theta$$
$$= 1 + \frac{\cos^2\beta}{\cos^2\gamma} - 2\frac{\cos\beta}{\cos\gamma}\cos\theta.$$

Equating the two preceding equations and simplifying,

$$\cos^2\beta + \cos^2\beta\left(\frac{1}{\cos^2\gamma} - \tan^2\gamma\right) - 2\cos\beta\left(\frac{\cos\theta}{\cos\gamma} - \sin\beta\tan\gamma\sin\alpha\right) = 0.$$

Simplifying further,

$$2\cos^2\beta - 2\cos\beta\left(\frac{\cos\theta}{\cos\gamma} - \sin\beta\tan\gamma\sin\alpha\right) = 0$$

or

$$\cos\beta - \frac{\cos\theta}{\cos\gamma} + \sin\beta\tan\gamma\sin\alpha = 0$$

or

$$\cos\theta = \sin\alpha\sin\beta\sin\gamma + \cos\beta\cos\gamma.$$

* See page 331 of original paper.

Microphotometer Data

Ramie—002

TABLE I. RAMIE—002. LAMP CURRENT: 3.7 AMP.; SLIT DIMENSION: WIDTH, 0.6 MM.; AVERAGE LENGTH, 0.5 MM.; SHUTTER CLOSED: READING, 1.00

Angles	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	Average	I (Average deflection)	Optical density	%
0	1.08	1.11	1.11	1.06	1.09	0.09	1.508	31.60
5	1.14	1.20	1.20	1.11	1.16	0.16	1.257	26.32
10	1.41	1.48	1.43	1.36	1.42	0.42	0.840	17.56
15	2.21	2.35	2.18	2.08	2.20	1.20	0.383	8.02
20	2.63	2.82	2.80	2.60	2.71	1.71	0.229	4.79
25	3.00	3.00	2.92	3.00	2.98	1.98	0.1650	3.46
30	3.12	3.35	3.37	3.19	3.26	2.26	0.1076	2.25
35	3.50	3.60	3.25	3.52	3.47	2.47	0.0691	1.45
40	3.68	3.80	3.83	3.58	3.74	2.74	0.0239	0.50
45	3.38	3.47	3.58	3.59	3.50	2.50	0.0639	1.34
50	3.47	3.50	3.88	3.82	3.67	2.67	0.0352	0.74
55	3.64	3.64	3.75	3.53	3.64	2.64	0.0400	0.83
60	3.66	3.74	4.12	3.75	3.82	2.82	0.0113	0.24
65	3.25	3.46	4.07	3.90	3.67	2.67	0.0352	0.73
70	3.44	3.84	4.20	3.88	3.84	2.84	0.0083	0.17
75	4.00	3.68	4.33	3.70	3.93	2.93	0	0
80	3.72	3.77	4.47	3.97	3.98	2.98	0	0
85	3.60	3.82	4.36	4.00	3.94	2.94	0	0
90	3.65	3.75	4.22	4.20	3.94	2.94	0	0
							4.776	100.00

Microphotometer readings when the microscope was focussed on the lightest portion of the film between the 002 line and the next line of larger diameter:

3.75, 3.95, 3.88, 4.00 av. = 3.90

$I' = 2.90$

Ramie—101 and 101

TABLE II. LAMP CURRENT: 4.1 AMP.; SLIT DIMENSION: WIDTH, 1 MM.; AVERAGE LENGTH, 0.85 MM.; PLATE DISTANCE OF FIBER ELECTROMETER: 5 MM.; TENSION OF THE FIBER OF ELECTROMETER: 2.34; SHUTTER CLOSED: READING, 0

101 Angles	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	Average deflection	Optical density	%
0	—	—	—	—	0.22*	0.810	47.2
5	0.36	0.27	0.51	0.31	0.36	0.597	34.8
10	0.81	0.61	1.03	0.58	0.76	0.273	15.9
15	1.45	1.30	1.17	1.34	1.31	0.036	2.1
20	1.83	1.64	1.68	1.76	1.73	0	0
25	2.00	1.85	1.75	1.98	1.90	0	0
						1.716	100.0
101							
0	—	—	—	—	0.24*	0.773	43.7
5	0.42	0.25	0.27	0.38	0.33	0.634	35.9
10	0.85	0.55	0.64	0.78	0.70	0.308	17.4
15	1.43	1.06	1.12	1.45	1.26	0.053	3.0
20	1.62	1.36	1.28	1.63	1.47	0	0
25	1.99	1.40	1.24	2.09	1.68	0	0
						1.768	100.0

* The equatorial intensity of 101 and 101 is liable to error if the microscope is not exactly focussed on the middle of the diffraction ring. To remedy this, microphotometer readings were taken along an equatorial diameter; the results are given in Tables III, Series A, and III, Series B.

Microphotometer readings inside 101 ring:

0°	45°	135°	180°	180°	225°	315°	0°	Average
0.87	1.92	1.97	0.96	0.96	1.64	1.72	0.87	1.38

Microphotometer readings between 101 and 002 rings:

0°	45°	135°	180°	180°	225°	315°	0°	Average
0.77	2.40	2.06	0.75	0.75	2.06	2.16	0.77	1.465

$$I' = \frac{1.38 + 1.465}{2} = 1.42$$

TABLE III, SERIES A

Relative distance (cm.)	5.100	5.075	5.050	5.025	5.000	4.975	4.950
Reading	0.62	0.50	0.40	0.33	0.29	0.26	0.23
Relative distance (cm.)	4.925	4.900	4.875	4.850	4.825	4.800	4.775
Reading	0.23	0.22	0.21	0.22	0.24	0.31	0.37
Relative distance (cm.)	4.750	4.725	4.700	4.675	4.650	4.625	4.600
Reading	0.45	0.45	0.57	0.73	0.75	0.83	0.86

TABLE III, SERIES B

Relative distance (cm.)	5.025	5.015	5.000	4.99	4.98	4.97	4.96
Reading	0.36	0.33	0.30	0.27	0.26	0.25	0.24
Relative distance (cm.)	4.95	4.94	4.93	4.92	4.91	4.90	4.89
Reading	0.24	0.25	0.26	0.25	0.23	0.22	0.22
Relative distance (cm.)	4.88	4.87	4.86	4.85	4.84	4.83	4.82
Reading	0.21	0.22	0.22	0.23	0.24	0.24	0.25
Relative distance (cm.)	4.81	4.80					
Reading	0.27	0.30					

The values given in Tables III, Series A, and III, Series B, were plotted in the curve shown in Figure 1, and the microphotometer reading corresponding to equatorial intensity was ascertained.

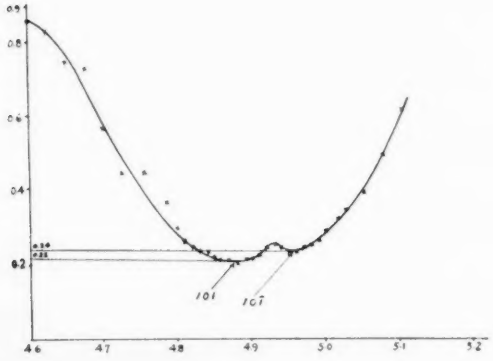

FIG. 1

Cuprammonium Rayon—002

TABLE IV. LAMP CURRENT: 3.7 AMP.; SLIT DIMENSION: WIDTH, 0.6 MM.; AVERAGE LENGTH, 0.5 MM.; SHUTTER CLOSED: READING, 1.00

Angles	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	Average	I (Average deflection)	Optical density	$\%_c$
0	1.85	1.80	1.86	2.00	1.88	0.88	0.518	17.60
5	1.80	1.87	1.90	1.90	1.87	0.87	0.523	17.74
10	1.94	2.22	2.15	2.20	2.13	1.13	0.409	13.90
15	2.50	2.40	2.55	2.65	2.53	1.53	0.277	9.43
20	2.54	2.55	2.80	2.85	2.68	1.68	0.237	8.06
25	2.73	3.15	2.92	3.00	2.95	1.95	0.172	5.85
30	3.07	3.25	3.08	3.14	3.18	2.18	0.1237	4.21
35	3.60	3.20	3.43	3.64	3.47	2.47	0.0690	2.40
40	3.46	3.24	3.40	3.55	3.41	2.41	0.0790	2.69
45	3.54	3.25	3.24	3.45	3.37	2.37	0.0977	2.98
50	3.30	3.36	3.60	3.65	3.48	2.48	0.0682	2.32
55	3.44	3.43	3.24	3.70	3.45	2.45	0.0734	2.50
60	3.57	3.50	3.30	3.55	3.48	2.48	0.0682	2.32
65	3.80	3.64	3.35	3.74	3.64	2.64	0.0400	1.40
70	3.50	3.42	3.60	3.56	3.52	2.52	0.0608	2.07
75	3.60	3.71	3.34	3.56	3.55	2.55	0.0551	1.88
80	3.80	3.56	3.85	4.00	3.80	2.80	0.0139	0.50
85	3.70	3.85	3.74	3.90	3.80	2.80	0.0139	0.50
90	3.50	3.60	3.66	3.60	3.59	2.59	0.0486	1.65
							2.947	100.00

Microphotometer readings when the microscope was focussed on the lightest portion of the film between the 002 line and the next line of larger diameter:

4.05, 3.50 (rejected), 3.85, 3.80 av. = 3.90

$I' = 2.90$

Cuprammonium Rayon—10$\bar{1}$

TABLE V. LAMP CURRENT: 3.7 AMP.; SLIT DIMENSION: WIDTH, 1 MM.; AVERAGE LENGTH, 0.85 MM.; PLATE DISTANCE OF FIBER ELECTROMETER: 5 MM.; TENSION OF THE FIBER OF ELECTROMETER: 2.34; SHUTTER CLOSED: READING, 0

Angles	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	Average deflection	Optical density	$\%_c$
0	0.40	0.40	0.39	0.43	0.405	0.435	21.10
5	0.42	0.40	0.42	0.47	0.43	0.410	19.90
10	0.51	0.47	0.49	0.54	0.50	0.344	16.70
15	0.61	0.56	0.66	0.64	0.62	0.250	12.10
20	0.78	0.72	0.80	0.82	0.78	0.150	7.30
25	0.94	0.87	0.94	0.98	0.93	0.0738	3.60
30	1.04	0.92	1.06	1.04	1.01	0.0378	1.86
35	1.05	0.99	1.14	1.07	1.06	0.0165	0.82
40	1.03	0.99	1.15	1.05	1.05	0.0208	1.01
45	1.08	1.00	1.03	1.11	1.05	0.0208	1.01
50	1.08	0.99	1.07	0.98	1.03	0.0291	1.41
55	0.90	0.85	0.96	1.08	0.95	0.0595	2.90
60	0.89	0.81	1.00	0.92	0.90	0.0878	4.27
65	0.84	0.92	1.01	1.01	0.94	0.0691	3.36
70	1.00	1.00	1.09	1.04	1.03	0.0291	1.41
75	1.01	1.05	1.14	1.15	1.09	0.0048	0.24
80	1.13	1.08	1.17	1.04	1.10	0	0
85	1.00	1.06	1.10	1.06	1.05	0.0208	1.01
90	1.12	1.07	1.14	1.17	1.12	0	0
						2.059	100.00

Microphotometer readings between 10$\bar{1}$ and 002 rings:

0°	45°	135°	180°	180°	225°	315°	0°	Average (I')
1.09	1.12	1.22	0.94	0.94	1.34	1.03	1.09	1.10

Cuprammonium Rayon – 101

TABLE VI. LAMP CURRENT: 3.6 AMP.; SLIT DIMENSION: WIDTH, 1 MM.; AVERAGE LENGTH, 0.85 MM.; PLATE DISTANCE OF FIBER ELECTROMETER: 5 MM.; TENSION OF THE FIBER OF ELECTROMETER: 2.34; SHUTTER CLOSED: READING, 0

Angles	1st quadrant	2nd quadrant	3rd quadrant	4th quadrant	Average deflection	Optical density	%
0	0.51	0.60	0.60	0.50	0.55	0.214	28.2
5	0.60	0.60	0.64	0.55	0.60	0.176	23.3
10	0.65	0.50	0.69	0.55	0.60	0.176	23.3
15	0.72	0.67	0.72	0.66	0.69	0.1155	15.1
20	0.84	0.73	0.87	0.75	0.80	0.0512	6.7
25	0.88	0.80	0.92	0.80	0.85	0.0248	3.4
30	0.90	0.90	1.04	0.82	0.91	0	0
35	0.90	0.90	1.06	0.78	0.91	0	0
40	0.88	0.83	1.10	0.80	0.90	0	0
45	0.92	0.83	1.07	0.82	0.91	0	0
						0.757	100.0

Microphotometer readings inside 101 ring: (Lamp current, 3.7 amp.)

0°	45°	135°	180°	180°	225°	315°	0°	Average
0.83	1.10	1.06	0.88	0.88	1.06	1.04	0.83	0.96

Average of this average and that between 101 and 002 rings $= \frac{1.10 + 0.96}{2} = 1.03$

Ratio of deflections for current 3.60 amp. to 3.70 amp. = 0.92:1.05

$$I' = 1.03 \times \frac{0.92}{1.05} = 0.90$$

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INDUSTRIAL SECTION

A Study of the Bleaching of Blue Cotton Fiber

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Abstract

The apparent cause and location of the color in blue cotton has been studied. The color which appeared to be located in the lumen was not particularly resistant to conventional scouring and bleaching agents. The controlling factor in the bleaching of blue cotton appeared to be lack of access to the blue color in the lumen by the treating solution. No ready means of rapid access to the lumen of the whole fiber was found. Diffusion of the blue coloration through the fiber appeared to occur slowly when the fiber was placed in a mildly alkaline bath at elevated temperatures. A bibliography is given.

Introduction

The literature was examined to uncover work done on the removal of the blue color from "blue cotton." The literature contains no reference to successful bleaching of blue cotton to a whiteness comparable to that of bleached white cotton. Conversations with finishing plant personnel and mill executives gave evidence that there was a general opinion that blue cotton could not be bleached.

It was thought advisable to assemble the known facts and conduct experimental work designed to explore with reasonable thoroughness the subject of the bleaching of blue cotton.

Nickerson and Milstead reported [4, 5] studies made which clearly indicate that exposure of cotton in the field to weathering seriously affects the grade of the cotton. A series of test samples from various parts of the Cotton Belt were examined after intervals of up to four months between opening and picking. In all samples, a reduction of two grades occurred after two months' exposure. A corresponding reduction in brightness and creaminess also occurred. Longer exposure caused a further lowering of grade.

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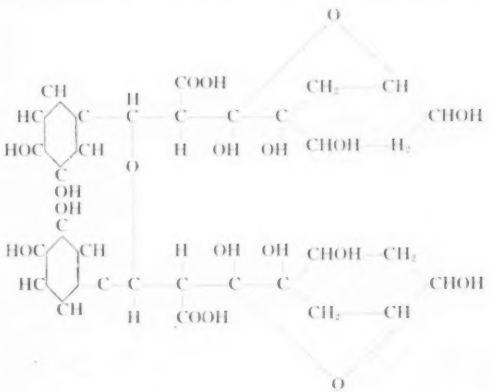
Oparin and Rogowin reported [8] the natural cotton pigments to be genetically related to chlorogenic



acid (see graphic formula) and in all probability are to be regarded as its oxidation products. Analytical work with cotton pigments has been confined to extracts from the cotton which indicate solubility in common solvents in general and more commonly in water and sodium hydroxide solution. It is quite possible that the color bodies, usually soluble in

common solvents, might be rendered insoluble under conditions developed by the fungus and also resistant to bleaching. The presence of chlorogenic acid in raw cotton has been definitely established. While chlorogenic acid appears to be readily soluble in hot distilled water or alkaline liquor, the oxidation products may be capable of imparting a fast color to the fiber. The color initially produced in the oxidation of chlorogenic acid is a yellowish brown and is capable of staining bleached cotton fiber to resemble raw cotton.

In reviewing the literature with respect to coloring matter in raw cotton, Turner [12] pointed out the possibility of developing dark-colored quinoid products through oxidation of hydroxyphenol groups such as are exhibited in chlorogenic acid. Turner further pointed out that pigmentary substances which go under the group name of melanins, more common in the animal world than in the vegetable world, appear to be connected with certain polymeric changes brought about by enzymes upon proteins such as tyrosine.

The production of melanin has been shown to involve the intermediate formation of derivatives of indole [2]. In the human body, indigo may be formed from indoxyl derived from indole in the presence of suitable agents [3].

Owen [9] reports in part: "Blue stain in cotton fiber may be caused by at least one fungus, a species of *Alternaria*. Staining of cotton fiber by this fungus is much greater during periods of high rainfall and excessive moisture." These conclusions were based on Mr. Owen's own experimental work in which he was able to produce the dark blue color in white cotton after sterilization of the sample and inoculation of the sample with a pure strain of the suspected fungus.

A variety of typical chemical agents were available for use in treating the blue cotton for removal of one or more normally occurring impurities. It was planned to try representative agents in various combinations in the attempt to remove the color from blue cotton. In a few cases, agents having no relation to commercial practice were used in the attempt to remove specific materials that might be present.

Methods of Testing

Testing was limited to visual inspection, photometer whiteness, and fluidity determinations. Results were compared with white cotton control standards.

Where visual inspection was inadequate, reflectance photometer readings were recorded in terms of magnesium oxide whiteness.

All fluidity determinations were made using a modified technique employing cupriethylene-diamine as the dispersant (as developed by Levy and Strauss [11] and patterned after A.S.T.M. Standard D539-40T [1]). The results were expressed in standard rhes.

Whiteness and fluidity data have been omitted in the interest of brevity since such information would add little to the present paper.

Methods of Treatment

The blue cotton was prepared for use as a crash-type toweling of loose construction in order to allow ready penetration by the treating liquors and yet present a reasonably uniform surface for subsequent examination. Similar samples of white cotton fabric in the grey were used where needed to establish the quality of the treatment liquors.

The bath-to-fiber ratio was in all cases approximately 100:1. The strength of the treating liquor was usually as high as or higher than that found in commercial practice. Thus the treating liquor had reserve strength or treating potential far in excess of that amount usually available and needed for satisfactory results on cotton fiber.

Appropriate aftertreatments were used as needed —*e.g.*, antichlor after hypochlorite treatment or dilute ammonia after acid treatment. The samples were air-dried.

The methods of treatment may be divided into the following categories:

1. *Treatments conducted in open vessels using the whole fabric.*—Samples of the grey fabric were prepared approximately 4 in. × 8 in. In general, the samples were treated in glass beakers in the water bath.

2. *Treatments conducted in closed vessels using the whole fabric.*—Samples of the grey fabric were prepared approximately 4 in. × 4 in. For treatment under pressure, the samples were treated in a stainless steel vessel. For treatment under vacuum, the samples were treated in conventional laboratory glassware. The degree of vacuum was obviously limited by the temperature of treatment. In order

to work liquor in and out of the lumen (if possible) the pressure or vacuum was intermittently released during the treatment.

3. *Treatments conducted in open vessels using cut fiber.*—Samples of the grey fabric were ground in the Wiley mill to pass through the 20-mesh screen to provide samples for these trials. After the treatments, the ground samples were collected for examination as mats on the Buchner funnel and air-dried.

4. *Treatments conducted in the launderometer using the whole fabric.*—In some cases samples were treated with a soap and alkali formulation as pretreatment or as aftertreatment to supplement some types of treatment given under category 1.

Experimental Treating Liquors

Listed below are the treating liquors applied to the blue cotton samples.

In the interest of brevity, aftertreatments to remove the treating agents have not been listed. However, aftertreatment and adequate rinsing in cool tap-water were used where needed.

Series A—Pretreatments

These pretreatments were designed to remove material associated with the cellulose of the cotton fiber. No analytical procedure was used to determine how completely such material was removed. Suitable wetting agents were used where needed to insure rapid wetting-out in aqueous media.

1. *Removal of wax and oil.*—Samples were extracted for 6 hours in the Soxhlet using alcohol or benzene. Separate samples were used for each solvent.

2. *Removal of pectic matter* [6, 7].—Samples were quantitatively extracted of pectic matter by means of treatment in 0.5% ammonium oxalate at 85°C for 24 hours.

3. *Treatment with enzymes.*—Samples were extracted under optimum conditions using proprietary enzymes claimed to be of value for the purpose of solubilizing proteins. Similar treatments were conducted using starch-solubilizing enzymes.

4. *Treatment with demineralizing agents.*—Samples were treated for 30 minutes near the boil in 1.0–5.0% solutions of mineral acids, ammonium bifluoride, and anion-sequestering complex phosphates.

5. *Treatments with detergents.*—Samples were treated with mild agitation in detergent mixtures representative of soap with alkali and of synthetics of adequate bath strength. Scour time was generally 30 minutes at temperatures between 70°C and the boil.

6. *Incubation treatment.*—Samples were wetted in 0.25%-dextrose solution, placed in covered petri dishes, and placed in the incubator at 37°C. The samples were removed after incubation for periods up to 168 hours and detergent-scoured in soap with alkali.

7. *Chlorination treatment.*—The treatment was conducted at room temperature for 1½ hours at a strength of 1 gram available chlorine (as sodium hypochlorite) per liter. Samples were prescoured with detergents, with removal of at least a portion of the water-soluble constituents of the raw cotton, in order to present a uniformly wetted surface.

8. *Treatment with pine oil-soap gel.*—Samples were padded with 10%-pine oil-soap gel, dried in the oven, and given a 1½%-caustic soda boil-out for 6 hours without pressure.

9. *Treatment for quantitative indigo removal* [10].—Some samples were treated in warm glacial acetic acid and others in warm pyridine. Since no color removal was noted, it was believed no indigo was present.

Series B—Caustic Boil-off

1. *Caustic boil-off.*—Samples were treated in 1.5% sodium hydroxide with pine oil-soap gel near the boil for 6 hours.

Series C—Bleach

1. *Peroxide bleach.*—Samples were treated 4–5 hours at 80°–85°C in silicate-buffered hydrogen peroxide baths (initial pH 10.3) using strengths of 0.25%–0.5% hydrogen peroxide. Where the lower strengths of hydrogen peroxide were used, two successive bleaches were used, each for the full time.

2. *Sodium hypochlorite bleach.*—Samples were treated for 1½ hours at room temperature in sodium hypochlorite solution containing 1.0 gram liter of available chlorine.

3. *Sodium chlorite bleach.*—(*a*) Acid chlorite—Samples were treated in 0.4% sodium chlorite acidified with acetic acid for one hour near the boil. (*b*) Basic activated chlorite—Samples were treated using a ratio of 1:1.25 of sodium chlorite to sodium

hypochlorite at a strength of 1 gram liter available chlorine. The solution was buffered with 0.3% of 5:1 ratio of sodium bicarbonate to sodium carbonate. Samples were treated for 1 hour below 35°C. The temperature was raised and the solution boiled for 15 minutes.

4. *Organic peroxide bleach.*—Solutions of succinic acid peroxide and of peracetic acid of adequate bleaching strength and optimum pH were prepared and used as bleach liquor on samples.

Series D—Reducing Treatments

1. *Alkaline reducing treatments.*—Samples were treated up to 4 hours using:

(*a*) 1% sodium hydroxide and 2% sodium hydrosulfite
(*b*) 2% sodium hydroxide and 4% sodium hydrosulfite
(*c*) 1% sodium hydroxide and 2% sodium sulfide

2. *Acid reducing treatments.*—Samples were treated for 1 hour near the boil in the following solutions:

(*a*) 5% zinc sulfoxylate formaldehyde
(*b*) 5% sodium sulfoxylate formaldehyde
(*c*) 6% zinc hydrosulfite

Series E—Post-finishing Treatments

1. *Launderometer scour.*—Previously finished (scoured and bleached) samples were scoured for 2 hours at 140°F in the launderometer using soap and alkali.

2. *Tinting with fluorescent dyestuff.*—Scoured and bleached samples were rinsed in solutions of the dyestuff at various low concentrations. The samples were squeezed, air-dried, and tested for whiteness.

Summary of Results

The results are summarized by methods of treatment as follows:

1. *Treatments Conducted in Open Vessels Using the Whole Fabric*

While some variation in final whiteness was found in the treated samples, whiteness in all cases was definitely inferior to that readily obtained on normal grades of cotton in a conventional manner.

Of the treatments used, the two-bath peroxide bleach and the launderometer detergent-scour gave the best results. One might suggest that better removal of blue color was obtained in a mildly alkaline bath of long duration because diffusion and removal of the blue color had time to take place.

Where the fluorescent dyestuff was used on a series of treated samples, a small improvement in whiteness was obtained, as determined on the reflectance photometer.

2. *Treatments Conducted in Closed Vessels Using the Whole Fabric*

Only a limited amount of work was done by this method. Efforts were confined to comparing the degree of whiteness developed by a procedure conducted in an open vessel with that by the same procedure conducted in closed vessel using alternate vacuum and pressure. No improvement was found over the open-vessel procedure.

It was evident that such methods did not aid in gaining access to the color in the lumen.

3. *Treatments Conducted in Open Vessels Using the Cut Fiber*

Excellent whiteness was readily obtained by using either the caustic boil followed by a peroxide and hypochlorite bleach or by using two successive peroxide bleaches. In many cases, the blue cotton samples were equal in whiteness to that of white cotton given the same treatment.

In most cases, the fluidity tests indicated excessive degradation of the cut fiber even before adequate whiteness was obtained.

It would appear that the blue color is located in the lumen of the fiber. The blue color is resistant only to the extent that it is inaccessible to normal finishing procedures. When the fiber is cut into short lengths, the liquor can more readily penetrate the collapsed lumen to remove the material containing the resistant color.

4. *Treatments Conducted in the Launderometer Using Whole Fabric*

The launderometer detergent-scour was given to a variety of treated samples of various degrees of whiteness. The whiteness of the samples was improved in all cases. The spread in sample whiteness

was less after the scour—that is, the low-whiteness samples were improved the greatest amount.

Discussion of Results

After grinding the blue cotton towel to pass through the 20-mesh Wiley mill screen, the conventional treatments bleached the samples to a whiteness equal to that associated with white cotton. A theory was immediately developed to tentatively explain this bleaching action.

In whole-fiber form the treating liquor reached the entire fiber surface and removed all surface material. In the cut or ground form the treating liquor was able, in addition, to reach into the lumen and remove all interior surface material due to the two open ends per cut piece of fiber. It is unreasonable to assume that the liquor was able to penetrate the cellulose fiber bulk from the inside lumen surface better than from the outside fiber surface. It is believed that only by removal of debris from the lumen is it possible to bleach the fiber to a high white (equal to white cotton). In order to remove the lumen debris, it is necessary to provide liquor within the lumen that will dissolve the debris and later bleach the insoluble residue within the lumen. Since the lumen is in a collapsed state, it is not apparent how liquor could be made to penetrate an inch-long microscopic canal and remove the colored debris.

Since extended detergent scouring in the launderometer of treated samples of whole fabric improved the sample whiteness, this may point to a very slow diffusion of the blue color through the swollen fiber wall.

Although the fluorescent dyestuff gave a small improvement in sample whiteness when used as an aftertreatment, this improvement was not great enough to yield a satisfactory product. There was too much residual blue color to be masked successfully by artificial means.

Conclusions

In this investigation much assembling of facts and exploratory work was done, not exhaustively but with agents readily available to the textile finishing plant capable of forcing the desired reactions without causing excessive damage to the fiber.

It was found that the blue color is probably developed through fungal action on the protoplasmic residue in the lumen of the fiber. The blue color is located in the lumen of the fiber. The blue color is not particularly resistant to the conventional bleach, as observed in treating the ground fiber.

The blue color will slowly diffuse through the fiber wall when swollen in a mildly alkaline bath—*e.g.*, a hot detergent-scour or a hot peroxide bleach.

Although the factors involved may have been found, no practical method of bleaching blue cotton to the degree of whiteness associated with bleached white cotton has been suggested as a result of this work.

The authors hope that the above report on bleaching blue cotton will stimulate further research on the problem. Comments by others who may have studied the problem will be welcomed and appreciated.

Acknowledgment

The authors wish to thank Mr. Ridley Piper of Fairfax Mill, Fairfax, Alabama, for his kindness in furnishing fabric samples, supplies, advice, and equipment. Thanks are also due to certain chemical suppliers for their generosity. Credit is due Mrs. Pauline Wortham, who conducted many of the procedures referred to in this paper.

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Announcement

Part II of the report "The Fungi Concerned in Fiber Deterioration," by P. B. Marsh, K. Bollenbacher, M. L. Butler, and K. B. Raper, which was scheduled for this issue, will appear in the August issue. Part I appeared in the June issue, page 313.

Evaluation of Roll Wool Felts for Arctic Footwear

Thora M. Plitt Hardy*

FELTS ARE ESSENTIAL to the warmth and protection of feet in cold climates, especially during wartime. In order to assist the Office of The Quartermaster General in maintaining the quality of arctic footwear in the face of expanding demands, threatened shortage of wool, and price considerations, the Fish and Wildlife Service, United States Department of the Interior, in 1943 cooperated in adapting, developing, and applying quality and wearing tests to standard and experimental felts submitted by the industry.

Fourteen samples of felts, approximately 1 yd. long each, were received. They included felts suitable for various parts of shoes—namely, tongue, vamp, midsole, and also inner sole. In general, 15 physical tests were utilized to evaluate each felt. The results have been assembled in Table I. Whenever possible, A.S.T.M. methods, Designation D 461-37 T [3*a*], were used. Certain modifications of these methods were necessary in view of wartime restrictions or other considerations, as indicated. Details of the tests are described below.

Sampling and Conditioning

Specimens were cut from various portions of the large sample, but away from the finished edges in order to obtain materials as representative as possible for testing.

All tests were performed under standard conditions (70° ± 1° F, 65% ± 3% relative humidity), except where otherwise stated in the methods. The samples were exposed to these conditions overnight (16 hours).

A. Weight Test

Ten 2-sq.-in. specimens, cut with a die, were taken at random from a large piece of felt. They were weighed separately on an analytical balance to the nearest mg. The average weight was determined and the standard error calculated. The standard deviation was found for each felt in order to ascertain its uniformity.

This test was based on the weight test for felts, A.S.T.M. Designation D 461-37 T [3*a*]. However, the number and size of the specimens were changed. Furthermore, to assure accuracy in these small specimens, a die with accurately squared corners was used.

B. Thickness Test

Five specimens of felt, measuring at least 2 sq. in. each, were taken at random. The thickness was measured by means of a compressometer which had a dial graduated to $\frac{1}{1,000}$ of an inch and a foot 1 in. in diameter. A pressure of 10 oz. per sq. in. was used and readings were taken 10 sec. after the load was applied. The average thickness, standard deviation, and coefficient of variation were calculated in order to determine the variability of the felt.

This test was based on the thickness test for felts, A.S.T.M. Designation D 461-37 T [3*a*].

C. Felt Density Test

The density of felt, expressed as percent density, was calculated from the data obtained in the weight and thickness determinations by the use of the following formula:

$$\% \text{ density} = 100 \times \frac{W}{T \times A \times 16.3871}$$

where W = weight (gms.) of 10 specimens, 2 sq. in. each, T = thickness (in.), A = face area of the specimens (40 sq. in.), 16.3781 = weight (gms.) of 1 cu. in. of water, and % density = 100 × specific gravity (s.g. of water = 1.00).

This test expression was developed by the American Felt Company [2].

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TABLE I. RESULTS OF TESTS ON

Use		Tongue	Vamps				
			(Woven felt)				(Vamps for quarters)
Felt number		I	II	III	IV	V	VI
Color		White	White	White	White-faced, khaki-backed	Light gray (*a*)	Light gray (*b*)
Average weight (gm.)	*A*	1.7	3.2	3.2	3.6	3.6	3.8
± Standard error of the mean		.02	.02	.01	.05	.04	.03
Standard deviation		.05	.05	.03	.15	.13	.10
oz./yd.²		19.9	36.9	36.9	41.0	41.5	43.6
Thickness (in. at 10-oz./in.² pressure)	*B*	.09	.17	.13	.18	.16	.15
Density (%)	*C*	28.1	29.0	37.3	30.2	34.0	38.4
Breaking strength—dry (lbs.)	*D*						
Length		53.5	114.5	91.5	106.0	89.0	222.8
1-in. width		56.5	101.0	103.5	127.0	92.0	150.0
Breaking strength—wet (lbs.)	*D*						
Length		38.5	77.0	74.0	69.0	69.0	147.3
1-in. width		37.5	68.5	68.0	83.0	62.5	116.0
Load for 25% elongation—dry (lbs.)	*E*						
Length		25.4	57.4	29.8	50.6	24.9	85.6
1-in. width		25.6	35.8	82.9	37.1	37.3	37.3
Load for 25% elongation—wet (lbs.)	*E*						
Length		8.0	15.8	10.3	24.8	13.5	25.0
1-in. width		6.3	12.9	35.5	14.3	15.8	13.5
Resistance to splitting—dry (lbs.)	*F*						
Length		—	—	—	—	—	—
Width		—	—	—	—	—	—
Resistance to splitting—wet (lbs.)	*F*						
Length		—	—	—	—	—	—
Width		—	—	—	—	—	—
Abrasion (in.)	*G*						
1,500 cycles		—	.04	.01	.05 (khaki) .05 (white)	.06	.06
6,000 cycles		—	—	—	—	—	—
Air permeability (ft.³/min./ft.²)	*H*	18.6	12.4	5.0	13.0	10.3	8.9
± Standard error of the mean		.92	.18	.07	.50	.42	
Standard deviation		2.9	.58	.21	1.6	1.3	
Water vapor permeability (gm./m.²/day)	*I*	946.7	848.1	887.6	907.3	867.9	848.1
Water permeability (ml./sec./5.1 cm.²)	*J*	—	.01		.04	.12	.09
Water absorption (% free moisture)	*K*	—	84.7	73.4	23.4	27.0	95.0
Drying (% free moisture after 2 hrs.)	*L*	—	42.2		4.6	6.8	61.6
Swelling (%)	*M*	32.0	17.0	5.3	9.9	8.6	41.4
Shrinkage (%)	*N*						
Length		12.5	7.5	3.8	1.6	0.0	5.0
Width		4.4	4.4	0.0	−1.6	−1.6	2.5
Thermal transmission	*O*						
Observed (cal./sec./°C m.²)		1.4	1.2	—	1.1	1.2	—
Computed (cal./sec./°C m.²)		1.5	1.2	—	1.1	1.1	—
Thickness (in. at 0.1-lb./in.² pressure)		.09	.18	—	.20	.19	—

* Extrapolated from 600 cycles.

† At this low head, 9½ in., the penetration was too slow to obtain figures.

COMMERCIAL AND EXPERIMENTAL ROLL WOOL FELTS

Midsoles						Insoles	
(Untreated)			(Treated)			(Untreated)	(Treated)
VII	VIII	IX	X	XI	XII	XIII	XIV
Gray	Med. gray	Dark gray	Light gray	Med. gray	Dark gray	Brown	Brown
12.4	9.0	8.2	11.0	9.6	8.3	5.9	5.5
.07	.19	.07	.03	.11	.07	—	.17
.23	.59	.21	.10	.36	.24	—	.52
141.7	102.7	94.2	125.5	109.8	94.6	67.8	62.5
.36	.35	.37	.37	.33	.35	.31	.32
53.3	39.2	34.4	44.9	44.7	36.2	27.2	26.1
223.5	245.0	214.0	280.0	255.0	199.0	86.2	74.4
277.0	193.0	183.0	249.0	212.0	187.0	146.0	81.5
168.0	198.7	167.0	205.0	178.6	148.0	80.0	50.0
193.0	158.5	107.0	178.0	138.0	140.0	67.7	66.5
155.7	134.5	128.8	150.8	132.0	98.0	112.5	33.7
98.2	96.3	43.5	112.8	84.5	64.5	33.4	21.3
59.2	64.3	60.5	83.5	29.8	42.8	22.3	18.0
41.0	34.0	20.3	50.3	18.4	34.0	39.5	11.7
55.1	66.1	49.4	75.6	62.0	37.5	—	24.5
53.9	59.7	44.1	71.9	59.7	36.2	—	26.8
48.0	54.7	41.9	69.0	55.3	34.9	—	22.0
46.0	50.5	35.9	64.9	52.1	32.1	—	23.0
—	—	—	—	—	—	.11*	.13*
.08	.09	.12	.08	.09	.16	—	—
1.3	2.5	7.8	1.4	2.5	4.9	—	23.2
.07	.05	.22	.05	.07	.12	—	1.4
.22	.17	.70	.17	.23	.37	—	4.5
591.7	631.2	690.3	591.7	690.3	690.3	—	788.9
.25	.07	.24	— †	.00	.02	—	—
35.9	12.0	19.0	9.0	8.0	12.7	—	26.2
16.9	3.9	4.4	1.6	2.5	2.5	—	—
8.0	7.1	5.2	3.0	5.5	12.0	7.6	7.0
0.0	1.0	2.3	1.6	0.0	1.6	0.0	1.6
0.0	−1.0	−2.0	0.0	0.0	0.0	3.1	0.8
1.2	1.1	1.0	1.1	1.1	1.0	—	0.9
0.8	0.8	0.7	0.8	0.8	0.8	—	0.8
.37	.35	.40	.37	.37	.37	—	.33

D. Breaking-Strength Test

Eight specimens,* 2 in. × 6 in. each, were cut so that 4 were taken in the lengthwise and 4 in the crosswise direction of the felt. A pendulum-type testing machine having a capacity of 300 lbs. was used. The jaws, which were 2 in. in width, were set 3 in. apart †; the speed of the pulling jaw was 12 in. per min. The breaking strengths of the specimens of felt were determined and the average strength in lbs. per in. width was reported separately for the lengthwise and crosswise directions.

This test was repeated using wet samples that had been submerged in water for 16 hours.

Care must be taken in cutting the width of the samples accurately with a razor blade. Slippage of the felt in the jaws or a break caused by cutting of the jaws must be guarded against by the use of padding when necessary and proper setting of the jaws.

This test was based on the breaking strength test for felts, A.S.T.M. Designation D 461-37 T [3*a*]. The length of specimens was decreased in order to conserve available material. However, the distance between the jaws of the testing machine at the start of the test was the same. Furthermore, a razor blade had to be used in lieu of a die.

E. Deformation-Load Test

An automatic recording device on the testing machine used for the breaking strength test rendered data in the form of a graph. From this graph the force necessary to produce an elongation of 25% in the felt was determined. The results were reported separately for the lengthwise and crosswise directions.

The test was repeated using wet specimens that had been submerged in water for 16 hours.

This test was adapted from the elongation test, A.S.T.M. Designation D 39-39 [3*c*]. Apparently, by reporting deformation load a better comparison of resistance to change between different felts could be made than by using the figures showing elongation at the breaking point.

F. Resistance-to-Splitting Test

Eight specimens, 2 in. × 5 in. each, were cut with a razor blade so that 4 were taken in the lengthwise and 4 in the crosswise direction of the felt. A pendulum-type testing machine, with jaws 2 in. wide separating at the rate of 12 in. per min., was used for this test. The specimen was prepared by splitting with a knife within the middle third of the thickness for a distance of approximately 2 in. from one end only. One of these lips was clamped in each jaw of the testing machine, the jaws having been brought close enough together for the purpose —approximately ½ in. apart. The number of pounds necessary to pull the 2 sections wholly apart was automatically recorded on the chart (Figure 1).

The test was repeated using wet specimens that had been submerged in water for 16 hours.

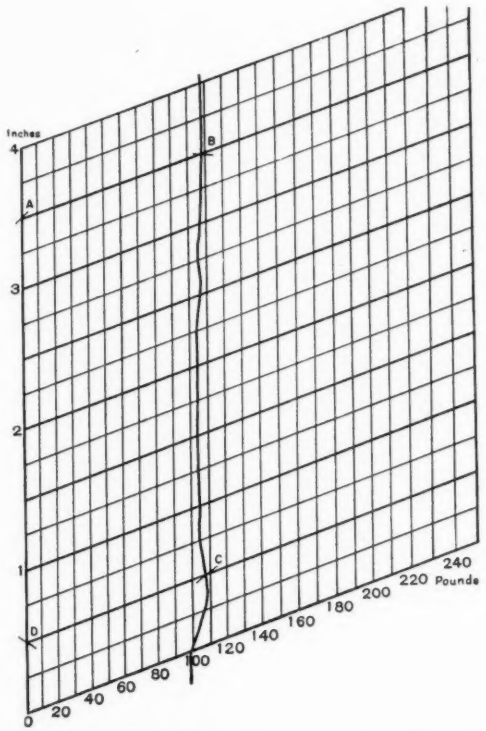

FIG. 1. *Chart showing resistance to splitting as recorded by machine.*

* The width of the sample was reduced to 1 in. on the thicker midsoles in order to stay within the capacity of the machine.

† In order to record the elongation on the graph, it was necessary to decrease the distance between the jaws to 1½ in. with some specimens.

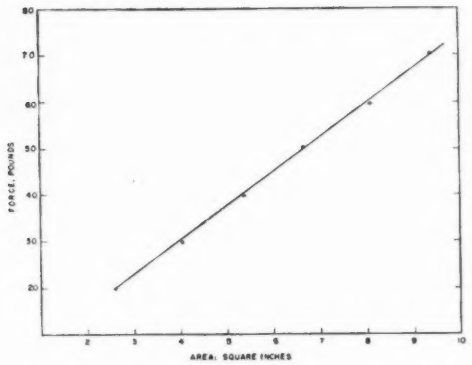

FIG. 2. *Graph for calculating splitting strength.*

The area enclosed by the curve on the chart (*ABCD*) was measured by means of a planimeter and the average splitting force (in lbs.) was found by referring to a graph (Figure 2) showing the number of lbs. plotted against the area enclosed by the curve. In order to obtain a more accurate determination, the automatic recorder was not started until the splitting force became nearly constant.

The procedure for this test was based, with minor deviations, on the splitting resistance test, A.S.T.M. Designation D 461-37 T [3*a*]. Calculation of the results from the data obtained on the machine was made by an accepted method in general use.

G. Abrasion Test

The abrasion machine used for this test was powered by a motor driven at a speed of 1,725 r.p.m. A $\frac{1}{4}$-in. brass plate, 9 in. × 6 in., sliding in ways horizontal and parallel to the abrasive surface, carried brass cylinders $2\frac{1}{2}$ in. long which were perpendicular to the abrasive surface. These cylinders were firmly fastened in six 2-in. openings, arranged in 2 parallel rows. $\frac{1}{2}$-lb. pressure per sq. in. was applied by weights fitted inside brass tubes $3\frac{1}{2}$ in. long. The pistons made a sliding fit in the cylinders fastened to the plate. Fiber-board discs, inserted $\frac{1}{16}$ in. from one end of the tube, held the felt specimens.

Five specimens of each felt were cut with a circular die having a diameter of $1\frac{3}{4}$ in. A clearance of $\frac{1}{8}$ in. was left between the end of each tube and the abrading surface. The point of a small nail in the fiber board kept the specimen from turning; however, the specimens were rotated 90° every 1,000 cycles in order to insure uniform treatment. A counter was mounted on the machine in order to record each complete cycle. The specimens were abraded for 6,000 * cycles, moving a total of 8 in. for each cycle. The abrasive surface used was Crystal Bay Emery Cloth No. 3, made by the Minnesota Mining and Manufacturing Company. The loss in thickness was measured by a compressometer graduated to read to $\frac{1}{1,000}$ of an inch at a pressure of 10 oz. per sq. in.

FIG. 3. *Abrasion testing machine.*

This test was developed in cooperation with the Bureau of Animal Industry,† U. S. Department of Agriculture. The apparatus is shown in Figure 3.

H. Air-Permeability Test

Ten different locations on each felt were tested for air permeability, 2 determinations being made at each location. Two readings for every determination were taken, one at a pressure drop across the specimen of slightly below 0.50 in. of water and one at a pressure drop slightly above this figure. The value for the air permeability at a pressure drop of 0.50 in. was obtained by interpolation. The final results are expressed in cu. ft. per min. per sq. ft. of area at a pressure drop of 0.50 in. of water (= 0.018 lb. per sq. in.).

This test was based on the test for air permeability of textile fabrics, A.S.T.M. Designation D 737-43 T [3*c*]. The apparatus is described in the National Bureau of Standards Research Paper RP 1471 [7].

I. Water-Vapor-Permeability Test

A total of 6 specimens of each felt, in the form of discs each $1\frac{3}{4}$ in. in diameter, were tested. In order that moisture might pass through a known area, the felt was completely covered with melted wax except for an area of 1-in. diameter centrally

* For the thinner felts used for vamps it was necessary to reduce the number of cycles to 1,500.

† The holding arrangement of the abrasion machine was developed by John I. Hardy.

located on both sides of the specimen. The cover of the tin can was so placed on the felt specimen as to allow the unpainted area to show through the aperture, 1 in. in diameter, in the cover. A tin can, $3\frac{1}{4}$ in. high by $3\frac{7}{16}$ in. in diameter, was half filled with anhydrous calcium sulfate and the cover, with specimen firmly attached, was sealed to the can by melted wax. The sealed can was then weighed and placed in an inverted position on a rack located in the room controlled for temperature and relative humidity. The desiccant was thoroughly mixed at each weighing. Daily weighings were made until a constant rate of gain was established. Once stabilization was reached, the average for 3 successive days (usually the 5th, 6th and 7th days) was taken and the figure expressed in gms. per sq. m. per day.

It is important that the desiccant be placed in the cans while still slightly warm to prevent any possible uptake of moisture. It is also necessary that the seal around the can and the cover, as well as the covering of wax on the felt specimen, be airtight.

This test was based on the method described by Hobbs [5].

J. Relative Water-Permeability Test

A total of 10 specimens of each felt, 2 sq. in. each, were used on a hydrostatic instrument. Each specimen to be tested was clamped between 2 rigid metal plates, each plate having an aperture 1 in. in diameter. By means of rubber tubing connected to the aperture of the lower plate, the height of the head of water was varied and the permeability measured at 24 cm. and at 29 cm., the lower head being used to ascertain differences between felts through which the water penetrated readily. The water head was maintained at the desired level through the use of a calibrated glass tube filled with water; the upper end of this glass tube was sealed and the lower end ground to a point. The stopcock in the rubber tubing was opened simultaneously with the starting of a stop watch. At the appearance of the first drop of water on the upper surface of the felt, the stopcock was closed and the time observed. The average rate of penetration was computed in ml. per sec. per 5.1 sq. cm.

This test was based on the American Association of Textile Chemists and Colorists Tentative Hydrostatic Pressure Test [1]. The instrument used is shown in Figure 4.

K. Water-Absorption Test

Ten specimens, 2 sq. in. each, were die-cut from each type of felt. The specimens were weighed accurately to 0.1% of their total weight and submerged in distilled water. The water level was 1 in. above the vertically placed specimens and the temperature of the water maintained at 68° ± 2°F.

After 2 hours of submersion, the felt was removed from the water and centrifuged for 5 sec. The wire baskets on the centrifuge had a radius of 4.5 in. and completed 12 revolutions during the 5-sec. period. The specimens were then weighed in covered containers. The percent free moisture taken up was calculated by use of the formula:

$$\% \text{ free moisture} = 100 \times \frac{\text{weight of water absorbed}}{\text{weight of conditioned felt}}$$

A number of specimens were subjected to this test but at temperatures of 34° and 100°F and at pH ranging from 4.5 to 9.0 in order to observe the effects of temperature and pH upon water absorption. From the determinations it was found necessary to control both pH and temperature for the water absorbency test; hence, distilled water was used.

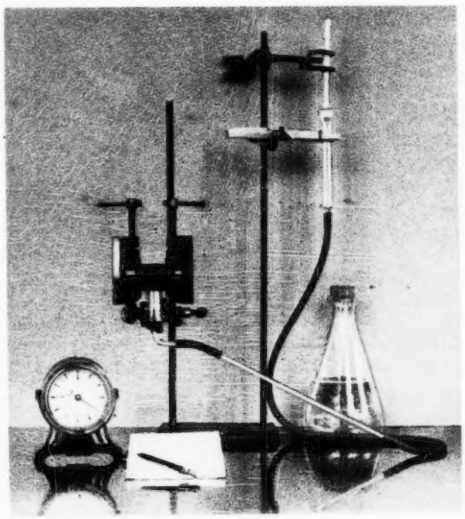

FIG. 4. *Hydrostatic instrument.*

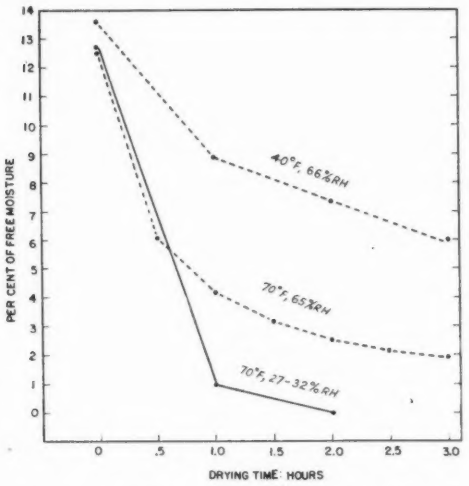

FIG. 5. *Rates of drying of felt sample XII under different conditions.*

L. Drying Test

Ten specimens, 2 sq. in. each, whose conditioned weights were known, were submerged for 1 hour in water maintained at 70° ± 1°F. The water level was 1 in. above the vertically placed specimens. The specimens were centrifuged and weighed as described in the water absorption test. They were then placed on wire racks so that they lay edgewise to a current of air which was controlled to flow at a constant rate of 3.3 m.p.h. The specimens were weighed at regular intervals until they reached a constant weight. A comparison between drying of felts was made on the basis of percent free moisture present at a definite time; the time chosen for comparison in this report was 2 hours.

Ten other specimens were similarly tested, except that they were dried in a refrigerated room in which the temperature was 39°–40°F and the relative humidity 66% ± 3%. An example is shown in Figure 5.

The details of this test were developed in this laboratory.

M. Swelling Test

Five specimens of felt, measuring at least 2 sq. in. each, were taken at random. The central area which was to be measured for thickness was outlined with a crayon or pencil. The thickness was obtained by means of a compressometer which had a dial graduated to $\frac{1}{1,000}$ of an inch and a foot 1 in. in diameter. The specimens were then submerged for 16 hours in water having a temperature of 70° ± 1°F. The specimens were dried and reconditioned and the thickness was measured at the same points as above. The percent swelling was calculated from the above measurements by use of the following formula:

$$\% \text{ swelling} = 100 \times \frac{\text{increase in thickness}}{\text{original thickness}}$$

This test was based on the water thickness swell test for roll wool felts, A.S.T.M. Designation D 461-40 [3*b*].

N. Shrinkage Test

Four specimens of felt, measuring 2 in. × 10 in. each, were cut so that 2 were taken in the lengthwise and 2 in the crosswise direction of the felt. The length of each piece was cut accurately. The samples were submerged in water (70° ± 1°F) for 16 hours, after which they were dried and reconditioned. The length of each piece was then accurately measured and the percent shrinkage calculated by the use of the formula:

$$\% \text{ shrinkage} = 100 \times \frac{\text{decrease in length}}{\text{original length}}$$

The percent shrinkage of the samples was reported separately for the 2 directions—crosswise and lengthwise.

This test was based on the water shrinkage test of roll wool felt, A.S.T.M. Designation D 461-40 [3*c*].

O. Thermal Transmission Test

One specimen of felt, 13 in. × 13 in., from each of the samples was taken for this test. Each specimen was tested, as a rule, in a series of 3 successive runs. The total number of runs on one specimen varied from 6 to 9 runs, depending upon the consistency of the results. A series of 3 readings for a particular felt was made on a given day. The total number of 9 runs represents readings taken on 3 different days. The felts were not treated or dried. As stated previously, they were left in an

atmospherically controlled room for a period of 16 hours prior to testing. The total test time for a series of 3 readings in one day was approximately 30 min.

The thickness of each specimen was obtained by using the same instrument and the same procedure as described in section *B*, (*Thickness Test*) with one exception—$^1/_{10}$-lb. pressures were applied instead of 10 oz. per sq. in.

In order to determine whether there was a relationship between the thickness of the felts and their thermal transmission, the theoretical thermal transmission values were computed according to the formula [6]:

$$T = \frac{1}{3.0t_{0.1} + 0.63} \text{ Btu (°F hr. ft.}^2\text{)},$$

where T is the thermal transmission and $t_{0.1}$ is the thickness at a pressure of 0.10 lb./in.^{2}. The results were then converted to cal. (sec. $\times$ °C $\times$ m.^{2}) for comparison with the observed values. The observed and the computed thermal transmission values were then plotted on a graph (Figure 6). The dotted line drawn at an angle of 45° indicates a 1 : 1 theoretical correspondence of these 2 sets of values.

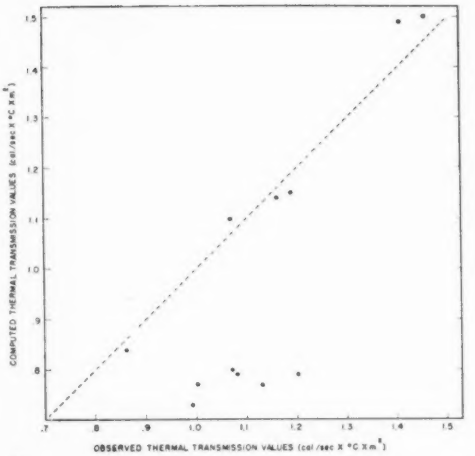

FIG. 6. *Computed thermal transmission values and observed thermal transmission values. The dotted line represents a 1 : 1 correspondence of these 2 sets of values.*

It will be noted from the graph that, whereas there is a close relationship between the thicknesses of some of the felts and their thermal transmissions, a number of felts do not exhibit this relationship.

TABLE II. RATING* OF FELTS FOR INDIVIDUAL TESTS

Test reference →		*A*	*B*	*C*	*D*	*D*	*E*	*E*	*F*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*
	Felt no.	Average weight	Thickness	Density	Breaking strength dry	Breaking strength wet	Load for 25% elongation dry	Load for 25% elongation wet	Resistance to splitting dry	Resistance to splitting wet	Abrasion	Air permeability	Water vapor permeability	Water permeability	Water absorption	Drying	Swelling	Shrinkage
Vamps																		
	II	4	2	5	3	3	3	5			2	4	4	1	4	3	4	5
	III	4	5	2	4	4	2	1			1	1	2		3	—	1	3
	IV	3	1	4	2	2	4	2			3	5	1	2	1	1	3	2
	V	2	3	3	5	5	5	4			4	3	3	4	2	2	2	1
	VI	1	4	1	1	1	1	3			5	2	4	3	5	4	5	4
Untreated midsoles																		
	VII	1	3	1	2	2	2	2	4	4	2	1	3	5	6	6	5	1
	VIII	4	4	4	4	3	3	3	2	3	3	3	2	3	3	4	4	2
	IX	6	2	6	5	6	5	4	5	5	5	6	1	4	5	5	2	4
Treated midsoles																		
	X	2	1	2	1	1	1	1	1	1	1	2	3	—	2	1	1	3
	XI	3	6	3	3	4	4	6	3	2	4	4	1	1	1	2	3	1
	XII	5	5	5	6	5	6	5	6	6	6	5	1	2	4	3	6	3

* Rating in point of excellence: (*A*) heaviest weight, (*B*) thickest, (*C*) most dense, (*D*) strongest, (*E*) highest load, (*F*) highest resistance, (*G*) smallest loss in thickness, (*H*) least permeable to air, (*I*) most permeable to water vapor, (*J*) least penetration of water, (*K*) lowest water absorption, (*L*) highest rate of drying, (*M*) lowest rate of swelling, (*N*) least shrinkage.

The latter were midsole felts which, were of a different construction from the others, as may be recognized by some of their other characteristics—*e.g.*, density, air permeability, and resistance to splitting. The lack of agreement with the theoretical formula in very dense fabrics of this type may be due to the need for a longer elapsed period of time before the taking of the final readings.

This test was based on the method described by Cleveland [4].

Results of Tests

The interpretation of the data shown in Table I is facilitated by arranging the felts in a series for each test, as presented in Table II. Consideration of the ratings of the physical test results of one felt as compared with another discloses that frequently several characteristics of one felt attain approximately the same grade. Thus, most of the characteristics of sample X rank very high—1 and 2—whereas those of sample XII rank low—5 and 6.

Water-repellent-treated felts, the so-called "waterproofed" felts, in general tended to be less permeable to water and also to absorb less water than the untreated felts. As a result of the lower uptake of water, the "waterproofed" felts also tended to dry in a shorter length of time. Air permeability and water vapor permeability did not appear to be affected by the waterproofing treatment.

Although the methods utilized for the evaluation of these felts yielded practical information, it would be desirable to know more about such other factors as flexibility of the felts and response to repeated loading (wearing quality) as well as fiber composition, as determined by microscopic analysis. However, at the time the investigation was under way there was no opportunity to perfect any further tests or to apply them to the materials; but they would constitute real contributions in this field.

Acknowledgment

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Some Recent Developments in Cotton Research at the Southern Regional Research Laboratory*†

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THE FINENESS, beauty, and utility of the cotton fiber have been recognized and desired by consumers for over 5,000 years. Yet cotton is not the oldest fiber in the world. About 50 centuries ago it was an obscure newcomer, appearing mysteriously in India to offer competition to the far more ancient fibers—silk and wool. The story of how cotton finally came to dominate the textiles of the modern world is old to everyone. The contemporary story of its threatened markets, after over a century of complacence, is also well known.

Some of the routes which scientific research is following in an effort to help cotton meet its present competitive situation will be indicated in this paper. Hope for cotton's future dominance of textiles will be warranted only if painstaking physical and chemical studies of the structure of the cotton fiber are made the basis for technological developments designed to so enhance the qualities of cotton that it can meet specific use requirements better than or at least on a par with its competitors.

Although the Textile Research Institute has remained true to its commitment to impartiality among textile fibers, I do not know of any other research group that has been more sincere in putting forward the profoundly important economic implications for our nation of research aid to cotton. In the ten years preceding World War II, this Institute was among the pioneer research organizations to recognize fundamental research on the physical and chemical properties of textile fibers as a prerequisite to a more advanced textile technology. The Southern Regional Research Laboratory of the U.S. Department of Agriculture devotes a great amount of time and energy to research on every phase of the development of greater usefulness of cotton.

A few examples of what has been accomplished at the Southern Regional Research Laboratory will show what has been done towards implementing research on cotton.

Objectives of Cotton Research at the Southern Regional Research Laboratory

Given the over-all objectives of maintaining, developing, and extending the usefulness of cotton, work on cotton lint at the Southern Regional Research Laboratory is of three general types. In the first line of work, fundamental knowledge is sought of the physical and chemical structure of the fiber, with the idea of establishing a relationship between basic properties and product performance. A second line seeks the formulation of chemical finishes which will enhance the natural fine qualities of cotton and improve other qualities in which cotton is not so well developed, or seeks chemical modifications of cotton which will create entirely new characteristics. The third line is mechanical-processing research to develop new or improved machinery for the more efficient and economical manufacture of high-quality cotton yarns and fabrics.

In all of these investigations, the Southern Regional Research Laboratory workers constantly evaluate their developments for use by industry, constantly confer with industry, and in many other ways cooperate with cotton manufacturers, from whom they receive valuable assistance in carrying experimental products and processes through the stage of commercial testing. Such collaboration is essential for the ultimate realization of their objectives.

Cotton Tire Cord

There is no other field in which all the phases of the problems facing cotton are better typified than

* Report of a study in which certain phases were carried on under the Research and Marketing Act of 1946.

† Presented at the Annual Meeting of the Textile Research Institute, New York, November, 1948.

‡ One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

in the tire-cord field. More cotton is consumed in the manufacture of tire cord than in any other single use. More competition has been met from rayon in this market than in any other market. The fundamental properties of cotton are involved in cotton tire-cord performance. Thus, the improvement of cotton tire cord through research conducted at the Southern Regional Research Laboratory is a good example of the contributions of this organization to the development of better cotton products. Our tire-cord studies range from the measurement and evaluation of individual properties through the production of experimental cords for wheel testing by tire producers; efforts are also made to improve the manufacturing equipment used by industry in manufacturing tire cord. A few of these developments are discussed in this paper.

Fundamental Investigations

One of the greatest opportunities for real improvement of the quality of cotton cords lies in the field of fundamental physical and chemical studies of the inherent properties of the cord. Varied investigations have been conducted of the interrelations of individual properties and of their influence upon the final performance of the cords in tires. Some of the more important studies have dealt with the effect of moisture, heat, and cord construction on the tensile and elastic properties of the cords.

Various studies of hysteresis, elastic modulus, and of elongation growth of cotton tire cord over a wide range of moisture and temperature have brought out a number of significant facts. In our experiments, in general, moisture contents over the ordinary ranges had a much greater effect on elastic properties than did temperatures up to 145°C. With the higher moisture contents, hysteresis and growth rate increased and elastic modulus decreased. (With increasing temperature, hysteresis increased slightly but persistently, and elastic modulus increased or remained unchanged.) The results obtained in these and similar studies have provided better criteria for determining the desirable properties of a tire cord in terms of performance. Low values for hysteresis, elastic modulus, and usually for growth rate are desirable.

We have studied heat as a deteriorating agent for cotton cords, both alone and in tires, and have compared the heat effect with that in rayon cords by comparing the respective fluidities in cuprammonium dispersion, breaking strengths, and elongations over a wide range of temperatures. Our results showed that prolonged heating of both cotton and rayon cords caused marked deterioration in a number of physical and mechanical properties, and that embedding the cords in rubber definitely reduced the rate of degradation. Specifically, loss of strength occurred in all the cords except in those heated only for short periods at relatively low temperatures. In every case, the extent of deterioration was progressively greater with increased time and temperature of heating. The protection afforded the cords vulcanized into the rubber tire carcass was presumably due to a reduction in the amount of atmospheric oxidation. Coating the cords with latex to improve adhesion did not provide any protection, and calendering of the skim stock, only a little. In general, cotton cords showed greater retention of strength than did rayon cords—strength of cotton after 256 hours at 120°C varied from 72 to 90 percent of the original, and of rayon, from 45 to 80 percent.

Extensive studies have been made of the influence of cord construction on cord properties. Cotton tire cord is a complex mechanical structure consisting of a number of single yarns twisted together to form plied yarns, or cables, and a number of these cables twisted together to form the cord. It is fairly common commercial practice to use 4 single yarns in the cable and 3 cables in the cord. It was found that variation in the number of single yarns from 5 to 3 and in the number of cables from 3 to 2 resulted in very little variation in the strength of the cords. However, the flex-fatigue life, as measured on two Southern Laboratory-developed flex machines, was decidedly greater for the 3-cable than for the 2-cable cord. With respect to elastic properties, the 2-cable constructions showed a lower hysteresis loss and a slightly higher elastic modulus. The amount of twist imparted to each component of the cord has an important bearing on the inherent strength, elongation, and fatigue resistance of the cord as a whole. For example, it was discovered that a lower than normal twist in the singles yarn resulted in a cord of longer fatigue life. A group of experimental tires made with a cord having less than the conventional twist in the singles yarn had exceptionally good fatigue life in indoor wheel tests, run with above normal load, averaging 27 percent more mileage than the group of tires made with a cord having normal twist.

Chemical Treatments

High strength at elevated temperatures is desirable, particularly for tires for heavy-duty service in hot weather. A cotton tire cord having substantially improved heat resistance was developed at the Southern Laboratory by a practical modification of the mercerization process. The treatment is applied under specified conditions, preferably to yarns of a suitable special twist before their manufacture into cords.

Other research on chemical finishing in order to improve cotton tire cords has included an evaluation of lubricating treatments with respect to flexure endurance. It was found that lubrication increased flex life—using the Laboratory flexing machine, flex life was increased eight to ten times at room temperatures without affecting other cord properties. It is planned to evaluate the performance of lubricated cords in tires by indoor wheel tests.

Machinery Development

Another line of current tire-cord research is the development of machines to produce cord having more precisely the qualities needed in service or of machines to speed up the manufacture of tires or of tire cord. It should be emphasized that the Southern Laboratory works very closely with tire manufacturers, largely through an advisory group of seven representatives of the major tire companies.

Particularly desirable in a tire cord are uniform strength and a uniform amount of elongation under different loads. Rayon tire cords are better in this respect than cotton ones, and so considerable attention has been devoted to the problem of improving the uniformity of cotton cords. In one phase of this work, a new principle of stretching was applied and a device was developed which subjects the cord to constant tension during stretching rather than to the constant percentage of stretch usually applied. The device permits a variable rate of stretching. It operates faster than other stretching machines and, above all, produces a more uniformly strong and more uniformly elongating cord. Manufacturers of cotton tire cords have shown great interest in this new machine and several are evaluating its possibilities for commercial operation. See Figure 1.

Research improvements in tire cords can be finally evaluated only by service tests on experimental tires. In commercial tire manufacture, long yardages of cord fabric are required for loading the dipping, drying, and calendering machines, so that in the manufacture of one or two experimental tires more than a hundred pounds of cord are used. Several large rubber companies have been cutting down development costs and production time by using a special machine for building plies from small quantities of cords, which permits bypassing of the regular dipping, drying, and calendering machines. On the basis of information obtained from one of these companies, Southern Laboratory engineers have designed and constructed a ply-building machine and have incorporated a number of features which permit more efficient and faster operation. The cord is dipped, dried, and formed into a ply with rubber in one operation. The quantity of experimental cord required is only slightly more than that contained in the experimental tires—the ply can be built from a single spool of cord instead of from more than 1,000, as required for processing in the usual manner. This machine is now operating successfully at a plant in Mississippi and is producing tires for the evaluation of Southern Research Laboratory research.

Preservation of Cotton Against Degradation by Rotting and Weathering

One broad field of cotton research deals with the application of chemical finishes or modifying treatments to cotton so as to improve its present properties or to create entirely new properties. There are two major qualities in which cotton does not give entire satisfaction to consumers—namely, its resistance to rotting and its resistance to weather. Yet because of other properties cotton is desirable in uses which subject it to degradation due to rotting and to weathering.

Rotproofing Cotton

There are many known treatments which improve cotton's resistance to rotting by impregnating it with various chemicals. Nearly all of these have the disadvantage of imparting qualities to the finished product which limit its usefulness—for instance, they produce objectionable color, odor, or stickiness, or render the material poisonous. An entirely different type of treatment is one which modifies the fiber itself and produces the desired effect by a change in the composition of the cellulose. A new compound is formed by this treatment which is extremely resistant to rotting.

The treatment which the chemists of the Southern Regional Research Laboratory have developed is accomplished by partial acetylation. This involves the conversion of cotton cellulose in the form of fiber, yarn, or cloth directly by chemical reaction in a bath containing acetic anhydride, glacial acetic acid, and a catalyst to a modified cellulose in which some of the hydroxyl groups are replaced by acetic acid radicals, without loss of fibrous or other textile properties. Thus, part of the cellulose in the cotton is converted into cellulose acetate, a substance which apparently does not tempt the appetites of rot-producing organisms. Beside its advantage over other rotproofing treatments in enabling the fiber to retain the form and appearance of plain cotton, the treatment does not produce any of the objectionable odor

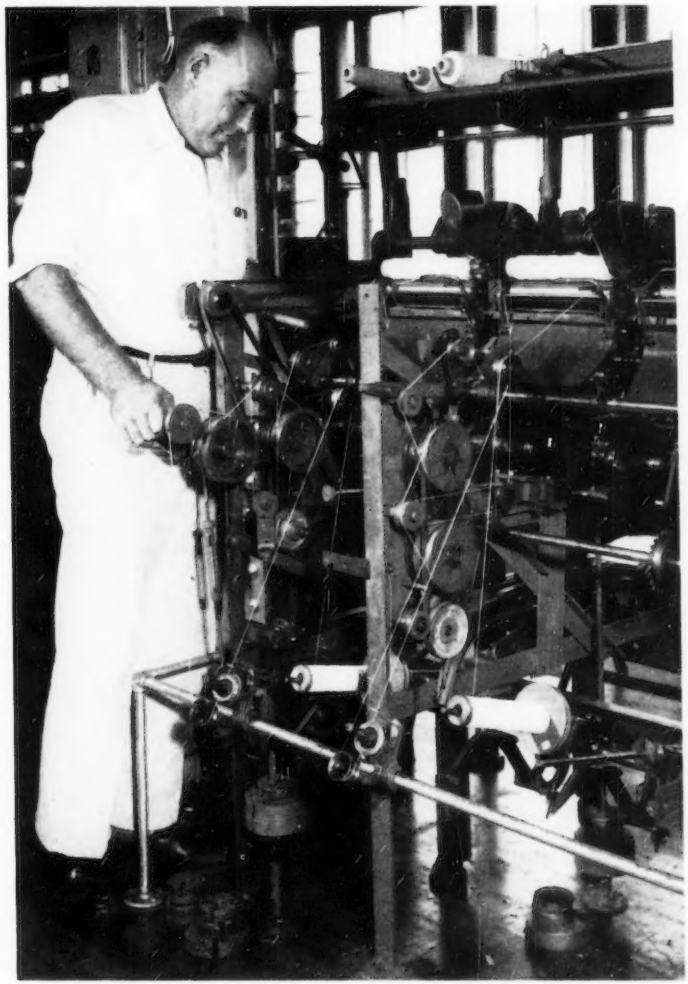

FIG. 1. *Two models of the Southern Regional Research Laboratory tire-cord stretching apparatus in operation on a conventional winder.*

or appearance caused by the usual treatments. A sufficient degree of acetylation (20–30 percent of acetyl) produces virtually a new fiber with new properties which is adaptable to additional utilizations. Present laboratory investigations are centered on simplifying and speeding up the process. This is being approached by attempts to apply the treatment by continuous methods instead of by the batch methods now used.

Application of the partial acetylation process to cotton was first tried in England; but the Southern Laboratory was the first laboratory in the United States to explore thoroughly its rotproofing possibilities. During the war the acetylation treatment was first applied to cotton sandbags of the type used in military operations. Tests of the treated bags piled in stacks on the ground in New Orleans demonstrated the superior resistance to rotting of partially acetylated cotton in contact with the destructive forces in the soil. The surface fabrics of the bags at the bottom of piled stacks fully exposed to weather for 2 years retained from 35 to 40 percent of their breaking strengths. Surface fabrics of bags at the top of the stacks retained from 35 to 100 percent in contrast to complete deterioration of untreated bags in one-fourth the time. The amount of resistance to rotting by acetylated materials depends somewhat upon the variables of the method as well as upon the degree of acetylation.

Samples of acetylated materials are continually sent out from the pilot plant of the Southern Laboratory for industrial trials. One use is in bags of the type used to carry water-softening agents. Untreated cotton already possesses high abrasion and tear resistance, easy and rapid drainage, and good filtering action—qualities needed in this use; but water-softening bags must above all be rot- and mildew-resistant, nontoxic, and must not affect taste. Cotton modified by partial acetylation meets all of these requirements. Treated cotton bags have lasted a year, in contrast to one month or even a week for untreated bags. An Indiana manufacturer, aided by Southern Laboratory engineers, has started a small commercial production of these bags using a modification of an ordinary laboratory wash wheel for the acetylation process. The fishing industry, which is trying acetylated cotton cord, rope, and gill nets in service in various waters, reports favorably. A trial of acetylated cotton linings in men's shoes is in its second year, with encouraging results reported. One company has evaluated acetylated shoe lining for abrasion resistance and reports that it may have some advantage over ordinary cotton in this property. Another industrial application of acetylated cotton is as a re-enforcing material in plastic laminates, in which its good resistance to heat and electricity and its good dimensional stability are of importance.

The industrial trials of partially acetylated cotton goods demonstrate the value of research developments to industry and the corresponding value to research organizations of the cooperation of manufacturers.

Weatherproofing Cotton

In the weatherproofing field, Southern Laboratory research has made a valuable contribution to the fundamental knowledge of the mechanism by which cellulose breaks down during exposure to weather and of the nature of the influence on cotton of chemical treatment to prevent degradation. The action of weather on cotton is extremely complex and variable. In dry places, sunlight is the principal destructive force, whereas in warm, moist climates mildew and rot may be a contributing or a major cause of failure. In fact, chemical treatments which are effective rotproofing agents sometimes actually promote decomposition due to weather.

Patterns of Degradation. Data which had been collected over a period of 5 years were assembled and interpreted in 1946 of tests of representative cotton fabrics, some untreated and some chemically treated, exposed outside on racks in the warm, damp climate of New Orleans. Compounds evaluated included fungicides, water-repellents, and ultraviolet-screening pigments. The changes in breaking strength and in fluidity of the various samples were correlated and it was found that they showed a definite relation. Patterns of weathering degradation were established for different types of fabrics. These patterns are proving useful in the formulation of protective finishes.

Degradation by Light. In studies at the Southern Laboratory the effect of sunlight was isolated from the other degrading effects of weather. Use was made of a special rotating cabinet which excludes wind, rain, dust, and microorganisms and exposes the cotton fabric samples continuously throughout the day to the rays of the sun. It exposes samples behind 6 glass windows, each one having a different

color and, therefore, transmitting a different fraction of sunlight. In this cabinet samples were exposed to the energy of five different spectral regions as well as to total solar radiation. From the data collected on the radiant energy incident upon each sample and on the chemical and physical evidences of deterioration, it appeared that the energy from some parts of the spectrum (the ultraviolet rays) is more damaging than that from others; also, that rays of certain wave lengths may interact in such a manner as to reduce the net degrading effect of their combined incident energy. Similar data have been obtained with the use of a carbon arc lamp as a source of radiation and Corning glass filters as a means of obtaining certain selected spectral regions of incident energy.

Army Ducks and Shade Cloth. Current weatherproofing research is being directed towards the formulation of protective finishes for army awning ducks and tobacco shade-cloth—two uses in which good resistance to sunlight is particularly desirable.

In research on protective finishes for cotton ducks, the following types of treatment have been tested: clear resins alone, mineral pigments alone, and combinations of resins and pigments. The tests were made at four geographical locations. Plain urea formaldehyde resin gave definite protection to undyed or solid-dyed fabrics and a combined resin-pigment treatment (urea formaldehyde-lead chromate) gave even greater protection. With this resin-pigment combination less than 5 percent of strength was lost after a year's exposure compared with a 50 percent loss by untreated fabrics. In the treatment of colored, striped awning ducks, the treatment must not introduce an interfering color, and, hence, only clear, light-absorbing resins have been tried. The effectiveness of urea-formaldehyde resin in this type of treatment was indicated and studies are being continued.

Research on tobacco shade-cloth was made a phase of weatherproofing work at the specific request of a group of Florida tobacco growers. About 60 million yards of tobacco shade-cloth are produced annually from cotton. If tobacco growers can obtain an economical treatment to prolong the service life of the cloth, undoubtedly larger acreages of tobacco would be shade-grown, thereby providing an extension of cotton's use in this market.

It was known from previous work that the light waves which damage cotton can be absorbed by various mineral pigments and film-forming resins. Since the finishing of tobacco shade cloth presents certain processing difficulties because of its light construction and great width, relatively simple pigment or pigment-resin treatments were tried. Precipitation of lead chromate in the fabric appeared the most effective in tests which used about 10,000 yards of cloth in the 1948 season in Florida tobacco fields—lead chromate-treated cloth lost only 25 percent of its strength in contrast to 70 percent by untreated cloth. Tests of much larger yardages of the treated cloth will be conducted in Florida this season. This work is another illustration of the benefits to be derived by both scientists and agricultural groups from cooperative experiments.

Water-Resistant Cotton by Self-Sealing Through Swelling

In many of its outdoor uses cotton is exposed under conditions where resistance to water is of the first importance. Improvement of this quality will be a major necessity if cotton continues to be faced with its present competition. This problem is therefore being approached in current work at the Southern Regional Laboratory.

Impermeability of cotton fabrics to the passage of water is being sought largely by virtue of a self-sealing effect of cotton upon swelling in water. Three lines of approach are being studied: (1) selection of the cotton varieties best adapted to self-sealing; and or (2) treatment of the yarns before weaving with various insoluble "swellable" finishing agents to induce a greater amount of swelling; and or (3) use of a more densely woven cloth—one with more filling threads per inch than in conventional weaves.

The present research is the outgrowth of a successful wartime project in which the swelling property of cellulose was utilized to produce a cotton fabric sufficiently watertight for the manufacture of rubberless cotton firehose (of the sort used commonly in emergency installations). In earlier work the self-sealing effect upon swelling the fibers in water, serving to close up the minute spaces between the fibers in the yarns, was augmented by the addition of a swellable finishing agent before weaving, hydroxyethylcellulose being found the most effective. Because of the satisfactory performance of the all-cotton firehose, the U.S. Quartermaster Corps requested continuation of the work to develop lightweight, water-resistant fabrics for outdoor use. This

was approached through a search for cotton varieties more suitable than others for utilization of self-sealing by swelling—that is, those having the greatest capacity upon wetting to close up the spaces between fibers and thus render the yarns, or the cloth, more resistant to penetration by water. In early work, the discovery was made that not only might differences in the swelling property be expected from variety to variety but also from the immature to the mature fibers of the same variety. This was revealed by use of a specially designed apparatus that measures the quantity of water which, under constant pressure, will seep through a weighed bundle of yarn or of loose fiber tightly packed into an orifice. By means of this orifice test it was demonstrated that seepage of water through bundles of equal weights of mature and immature fibers from any variety of cotton was from three to seven times greater for the mature than for the immature fibers.

It is indicated that swelling is not the only important factor influencing the orifice test—fiber shape and size may greatly outweigh the influence attributable to differences in the absolute swelling values of different cottons. But since, in any case, the final closing capacity of fabrics from thin-walled cotton is greater than that of fabrics from thick-walled cotton, it has been decided that closing capacity, representing a resultant of all pertinent effects, is useful for the evaluation of cotton varieties for the production of water-resistant fabrics.

In making application of these findings, fabrics have been woven, using conventional constructions, from yarns which were indicated by orifice tests as having a good degree of impermeability. A water-repellent agent has been subsequently applied, or, before weaving, highly swellable finishing agents have been added to the yarns—such as hydroxyethylcellulose, as used in the production of the unlined cotton firehose which we developed during the war. In some cases, the treated yarns were woven into fabrics of an unconventional (extra dense) construction by the use of a special loom attachment developed by the Southern Laboratory. In preliminary tests, fabrics woven from yarns containing immature fibers have shown distinctly superior water resistance as compared to fabrics of identical construction from mature fibers. This finding is expected to be of considerable importance since it may provide a new outlet for the immature or thin-walled cottons which are now considered inferior for most uses.

In the microscopical studies of fiber cross-sectional swelling a special dye technique was used which differentiates between mature and immature fibers by cross-dyeing of the fibers with red and green dyes in the same bath. Approximately 60 mills are now using this test and some are testing every lot of cotton purchased in order to separate the mature, or thick-walled, from the immature, or thin-walled.

Development of New Properties Through Chemical Modification

The improvement of individual properties of cotton fiber is sought through the introduction of specific chemical groups into the cellulose molecule to replace or to combine with a number of the hydroxyl groups present. The conversion of part of the cellulose in cotton to the rot-proofed compound, cellulose acetate, is one example of this. In the same manner, other properties of cotton have been improved through the formation of cellulose derivatives.

The introduction of amino groups into the cellulose molecule has produced a type of cotton which has an affinity for acid wool dyes, in contrast to ordinary cotton, which has not. Moreover, metallic elements added to aminized cotton gives rot resistance; addition of organic groups gives water repellency; and there are other possibilities for further modification. Cotton may be aminized in the form of fiber, yarn, or fabric by allowing 2-aminoethylsulfuric acid to react with the cellulose in a strongly alkaline solution, followed by heating and washing. Breaking strength is not appreciably affected. The use of aminized cotton as an anion exchanger is being investigated.

Cotton fabric that absorbs water at a much faster rate than ordinary cotton has been obtained by an optimum procedure worked out for the formation of carboxymethylcellulose. Carboxymethyl groups are introduced by treating yarn or cloth with alkali and small amounts of chloracetic acid. The reaction takes place without loss of fibrous properties and very little loss of strength. The treatment increases water absorbency and definitely speeds up the rate at which the water is absorbed. This property should be of value in such fields of utility as the towel industry.

It is of interest in this connection to refer to another well-publicized technique which originated at the Southern Laboratory—namely, the method for measuring the rate of water absorption by cotton

fabrics, which a cooperating finishing company has now adapted to use with toweling.

Methanolysis of cotton cellulose in the presence of anhydrous acid produces a new type of short-chain cellulose molecule which is resistant to further action of strong alkalies.

The phosphorylation of cotton cellulose, originally accomplished as part of a wartime project which successfully produced flameproofed cotton, has been carried out by a treatment combining the application of heat with the treatment by urea and phosphoric acid. Cellulose phosphate has also been prepared by using phosphorous oxychloride in the presence of pyridine. It has been demonstrated that phosphorylated cotton is a good cation exchanger.

Cotton Processing Research

At the experimental cotton mill at the Southern Laboratory attention is constantly given to the opportunities for getting more uniform cotton products at every stage of production—from the time the matted lint enters the opening machine through all the steps of processing into yarns and fabrics. Improvements in the uniformity of cotton yarn, cords, and fabrics obviously would raise their quality and add to the serviceability of the finished product. Also, greater uniformity at the various stages of the manufacturing processes, by increasing production efficiency and reducing costs, would place cotton products in a stronger competitive position.

In a series of drafting studies it has been found that while increases in draft on the drawing and roving frames do not affect materially the strength or grade of a coarse yarn, increases in draft during spinning result in significantly lower skein strength, although there is little or no effect on the grade of the yarn.

The growing substitution of machine-picking for hand-picking of cotton has made imperative the development of more efficient equipment for cleaning ginned cotton in the textile mill. As a step towards this, attempts are being made to establish some fundamental principles of cleaning. Studies have been made on the characteristic adherence of cotton fibers to trash and the electrostatic potential of the many types of trash particles—fuzz, twigs, sand, dirt, bits of stalk, and especially the leaf material which is particularly hard to remove. In the course of work on this problem an improved cotton-opening machine has been developed which fluffs up matted lumps of cotton into small, soft tufts in order to prepare them for subsequent cleaning. So far, the indications are that the increased fluffiness is achieved without damage to the fibers. The design of the machine is flexible enough for use in getting information of research interest on each lot of cotton. Actually, trash removal is only incidental to the real function of the machine—the more efficient opening up of the matted cotton. Further study is being given to the more effective removal of impurities from the opened cotton.

Another development of mechanical processing investigations is that of a radical type of cotton-slashing machine designed and constructed for use in experimental slashing. The new machine dries the yarns by incandescent gas burners in an infrared, hot-air oven, in contrast to the steam-heated drums used in conventional slashing. The new slasher controls the rate of heating and offers better control of mechanical variables. This equipment gives promise of aiding in research on the factors which influence the final quality of slashed products. It is being evaluated in the Southern Laboratory. Its full capabilities have not yet been determined.

Conclusion

These typical research activities at the Southern Regional Research Laboratory may serve to indicate the profitableness to cotton of the quest for basic data concerning the character of the cotton fiber. Furthermore, they emphasize the role that can be played by scientists in helping cotton keep pace with the technological advances made by other fiber industries. Although this paper was limited to the developments at the Southern Laboratory, these are certainly representative of the many investigations being conducted by an encouragingly large number of other institutions engaged in research on cotton. Finally, they demonstrate significantly the mutual advantages to be gained through cooperation by science, agriculture, and industry.

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ABSTRACTS

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A list of periodicals, the abbreviations used in reference to articles, and the addresses of publishers of English-language publications is given in the January, 1949, issue, page 46.

ANALYSIS: TESTING: LABORATORY METHODS

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Flammability Apparatus

Testing apparatus for the evaluation of fire-resistant textiles. B. C. Rowley and M. Sonnino. *Am. Dyestuff Reptr.* **38**, 201–4 (Mar. 7, 1949).

In general, the directions for testing the fire resistance of a treated textile specify the exposure conditions but, with certain exceptions, do not indicate the mechanical means by which these conditions are to be produced. This situation may result in the failure of different laboratories to obtain strictly comparable test results. An apparatus for testing samples in a vertical, horizontal, or 45° position is described. The details of the apparatus, photographs, and results of tests made therewith are included. See also *Am. Dyestuff Reptr.* **38**, 78–84 (Jan. 9, 1949). C. A. A.

Text. Research J. July 1949

Plane Plastic Flow

The determination of stresses in plastic regions in problems of plane flow. P. S. Symonds. *J. Applied Phys.* **20**, 107–12 (Jan. 1949).

A simple numerical-graphic method for the calculation of stresses in plastic zones adjacent to boundaries of arbitrary shape is outlined, applicable to problems of plane plastic flow in ideally plastic materials. For illustration, the method is applied to determine the stresses in plastic zones near elliptic-free boundaries. The yield load of a tensile bar containing elliptic notches is obtained for a series of notches of varying sharpness. Some related problems are discussed briefly. Author

Text. Research J. July 1949

Continuous Moisture Measurement

Continuous measurement of sheet moisture. H. A. Sholl. *Tech. Assoc. Papers* **31**, 375–8 (1948) (through *Chem. Abstr.* **43**, 1186*f* (Feb. 10, 1949)).

Results obtained with the Moist-O-Graph under actual operating conditions are reported.

Text. Research J. July 1949

Transient Stresses in Photoelastic Materials

A method of assessing transient stresses in photoelastic substances. J. S. Stanton. *Rev. Sci. Instruments* **20**, 139–40 (Feb. 1949).

A method is given for measuring the transient stresses within photoelastic substances when the substances are subjected to any type of dynamic loading force.

L. P. Witnauer

Text. Research J. July 1949

Wax Content of Raw Cotton

Determination of wax content of raw cotton fiber—non-validity of preliminary treatment with hydrochloric acid. C. Lesslie, L. Hagan, and J. D. Guthrie. *Anal. Chem.* **21**, 190–1 (Jan. 1949).

The higher wax values obtained if cotton is first treated with the fumes of hydrochloric acid and then extracted with 95% ethyl alcohol by the Conrad method have been shown to be due to water-soluble non-waxy material. Cotton fibers should not be treated with hydrochloric acid prior to extraction of the wax. A. R. Macormac

Text. Research J. July 1949

CHEMICAL and PHYSICAL RESEARCH

★

Acetylation of Jute

Acetylation of cellulose in raw jute fiber. N. N. Saha. *Proc. Natl. Inst. Sci. India* **13**, 339–45 (1947) (through *Chem. Abstr.* **42**, 7039*e* (Sept. 20, 1948)).

The rate of acetylation of jute fiber is less than that for ramie, falling almost to 0 after the formation of

the diacetate. Lignin is present in the acetylated product and is responsible for the difference in structure from that of pure cellulose acetate.

Text. Research J. July 1949

Adsorption and Swelling Isotherms

An experimental and theoretical study of the adsorption and swelling isotherms of human hair in water vapor. H. J. White, Jr., and P. B. Stam. TEXTILE RESEARCH JOURNAL **19**, 136–51 (Mar. 1949).

Quantitative data on the length and diameter changes accompanying the adsorption of water by human hair are given as functions of the relative humidity. Data are also given on the effects of a load on the swelling isotherms. A theoretical treatment is proposed which accounts in a semi-quantitative way for the swelling isotherms and the effects of tension as well as for the adsorption isotherm. Authors

Text. Research J. July 1949

Allwörden's Reaction

Allwörden's reaction. Joel Lindberg. TEXTILE RESEARCH JOURNAL **19**, 43–5 (Jan. 1949).

The bubbles formed on the surface of the wool fibers in the Allwörden reaction are found to be due to a thin membrane located on the surface. The membrane is visible only under the electron microscope, and is different from ordinary wool keratin. The sensitivity of certain staining tests depends upon an increase in the otherwise very low permeability of the membrane to dyestuffs and other big molecules. Author

Text. Research J. July 1949

Elasticity of Fibers

The elasticity of textile fibers. *Bull. inst. textile France* **6**, 9 (June 1948) (through *Textil-Rundscahu* **3**, 325 (Sept. 1948)).

Measurements on 16 different fibers on the Micro-fiber-tester are shown in graphs and tables. The elasticity modulus, the % elastic work, the % elongation, and the strength in kg./mm.^{2} are given.

Text. Research J. July 1949

Elastic properties of cellulose fibers. R. W. Asmussen and F. Anderson. *Trans. Danish Acad. Tech. Sci.* **5** (47) (K 24) (through *Textil-Rundschau* **3**, 402–3 (Nov. 1948)).

Elasticity and plasticity of cotton fibers under static and dynamic loading were investigated at 0, 37, 70, and 100% R. H. and in water. The apparatus used (system Buchtal) is explained. Formulas are given for the stiffness and other mechanical fiber properties, and the results of the measurements are compared with those of other investigators.

Text. Research J. July 1949

Structure and Properties of Polymers

Molecular structure and the physical properties of polymers. C. W. Bunn. *Research* **1**, 630–40 (Nov. 1948).

A review.

Text. Research J. July 1949

Structure of Polyvinyl Alcohol

Crystal structure of polyvinyl alcohol. C. W. Bunn. *Nature* **161**, 930 (June 1948).

A new structure with a monoclinic unit cell was proposed for polyvinyl alcohol. The hydroxyl groups were found to lie randomly on either side of the zigzag hydrocarbon chain. Dimensions of the cell and atomic co-ordinates were given.

J. P. Tordella

Text. Research J. July 1949

Mechanism of Permanent Set

Chemical mechanism of permanent set. A. J. Farnworth and J. B. Speakman. *Nature* **161**, 890 (June 1948).

Permanent set acquired by strained wool fibers in steam is ascribed to hydrolysis of the disulfide bonds followed by condensation of the products with basic side chains of lysine and arginine. Experimental results were given showing the essential role of the free amino groups in the cross-linking reaction leading to permanent set. J. P. Tordella

Text. Research J. July 1949

Retardation of Strength Loss in Cotton

Retardation of heat-induced strength loss in cotton yarns by liquid ammonia treatment. Harry B. Moore. TEXTILE RESEARCH JOURNAL **18**, 749–55 (Dec. 1948).

Treatments of cotton in the form of yarns and rovings with liquid ammonia are described. Smaller loss of strength as a result of prolonged heating at 160°C was found in these treated yearns. Since no strength changes were found in the fibers, it is concluded that this was due to a greater tendency of the ammonia-treated cotton to curl and crinkle, which increases the friction between the fibers in the yarn. Author

Text. Research J. July 1949

Shuttle Motion

Suggestion for the improvement of shuttle motion. Anon. *Textil-Praxis* **3**, 308 (Oct. 1948).

The speed not only of the shuttle but also of the parts of the picking motion must be accelerated. The energy loss is

$$U = \frac{m_1 m_2 (v_1 - v_2)}{m_1 + m_2}(1 - k^2);$$

where m_1 = mass of shuttle driving mechanism, m_2 = mass of shuttle, v_1 = initial velocity of parts of picking motion, v_2 = initial velocity of shuttle (= 0), and k = factor between 0 and 1, determined by elasticities of the propelling and the propelled body. (For the ideal elasticity of both bodies, $k = 1$.) This loss can be eliminated by: (1) taking the energy for propelling the shuttle from a relatively fast-rotating fly wheel mounted on the end of the lay; (2) use of a light, highly elastic picker ($k \rightarrow 1$).

Text. Research J. July 1949 J. F. Krasny

Tendering by Light

The action of light on cellulose acetate and nylon dyed with Duranol, Dispersol, S.R.A., and Solacet dyes. G. S. Egerton. *J. Soc. Dyers and Colourists* **64**, 336–41 (Oct. 1948).

A study has been made of the photochemical degradation of cellulose acetate and nylon yarns dyed with dispersed and soluble acetate dyes. Measurements were made of the losses in tensile strength of the yarns after exposure to sunlight in atmospheres of dry and moisture-saturated air. Dyeings were also exposed in atmospheres of dry oxygen, air, carbon dioxide, and nitrogen to a high-pressure mercury-vapor lamp. Many of the acetate dyes increase the degradation of nylon to a considerable extent, but have a very much less effect on the degradation of cellulose acetate. In several cases the loss in strength of the dyed cellulose acetate is less than that of the undyed yarn exposed under identical conditions. The photochemical degradation of both textile materials, whether dyed or undyed, is found to be due to oxidation processes. The acetate dyes that are particularly effective in increasing the degradation of nylon are capable of increasing the degradation of undyed cotton that is placed alongside, but not touching, nylon fibers dyed with these same dyes, and irradiated simultaneously. The dye may also be present on cellulose acetate, or as a dye film on glass. A much smaller effect is observed when undyed cellulose or nylon is irradiated in proximity to these acetate dyes. Cellulose acetate delustered with titanium dioxide also increases the degradation of undyed cotton irradiated in its vicinity. The slight influence of acetate dyes on the photochemical degradation of cellulose acetate and their greater effect on that of nylon are interpreted in terms of a theory involving oxidation of the textile material by activated oxygen and hydrogen peroxide. The relation between the fading of the dyed yarns and the degradation of the textile substrate is discussed, and it is pointed out that many of the dyes that increase the photochemical degradation of nylon are least fast to light on this fiber. Undyed cellulose acetate yarn delustered with titanium dioxide pigment and exposed to sunlight is degraded (loses tensile strength) to a much greater degree than bright, undyed cellulose acetate yarn. This is true when the exposure is made in both dry and in moisture-saturated air. C. Amick

Text. Research J. July 1949

Wool Damage by Microorganisms

Damage to wool blends by microorganisms. M. Nopitsch. *Melliand Textilber.* **28**, 233–7 (1947); cf. *C.A.* **42**, 8482*e* (through *Chem. Abstr.* **43**, 413*c* (Jan. 10, 1949)).

Fabrics containing wool fibers blended with Tiolan and rayon were subjected to the action of bacteria and fungi. The fabrics were inoculated with *Bacillus mesentericus* and the progress of the damage was followed by microscopic examination. The duration of the experiment was 3 mo. Untreated wool fiber and Tiolan were extensively damaged. Chrome-dyed wool was more resistant and rayon fibers were unaffected. Similar samples were inoculated with both bacteria and mold spores. Only the rayon was extensively damaged under these conditions.

Text. Research J. July 1949

Small-Angle X-Ray Scattering

Small-angle x-ray scattering in various cellulose fibers and its relation to the micellar structure. A. N. J. Heyn. TEXTILE RESEARCH JOURNAL **19**, 163–72 (Mar. 1949).

The study of the molecular structure of cellulose fibers by x-rays has been concerned until very recently with diffraction of only relatively wide angles. Almost no work has been done on the diffraction and scattering of x-rays within very small angles adjacent to the primary beam. The only fact known was that such "small-angle scattering" is produced by ramie and viscose rayon. In the present study, the small-angle scattering by various cellulose fibers has been investigated and it has been found that the scattering by different fibers is completely different. The hypothesis that the small-angle scattering in cellulose fibers would be related to the micellar size and distance is substantiated by the fact that an experimental change of those distances results in a corresponding (inverse) change in the extent of the scattering. On this basis the difference in the scattering patterns of different fibers is explained as a difference in the size and distance of the cellulose micelles or crystallites. An orientation of crystallites is also expressed in the small-angle diffraction pattern giving rise to the interesting phenomenon of "cross" formation when the crystallites form an angle with the long axis of the fiber. The angle between the intersecting lines of the cross proved to be related to the pitch of the spiral of the crystallites in the fiber. Author

Text. Research J. July 1949

BLEACHING: DYEING: FINISHING

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Sodium Chlorite as a Bleaching Agent

The behavior of sodium chlorite as a bleaching agent. I. E. Elöd and A. Klein. *Melliand Textilber.* **27**, 191–5 (1946); *Chem. Zentr.* **1947, I**, 379 (through *Chem. Abstr.* **43**, 1572*d* (Feb. 25, 1949)).

The action of $NaClO_2$ during long-continued bleaching treatments was studied. An optimum concentration of 0.5% on the weight of the fabric was used. Measurements were made of the degree of bleaching, fiber damage, average degree of polymerization, and the pH of the solution. The equilibrium pH was found to be 5–6. The bleaching effect corresponded to a good hypochlorite or H_2O_2 bleach and the cloth had a better appearance. This was especially apparent after 50 bleach washings. Fe, Cu, Pb,

and other metals affected the bleach less than when H_2O_2 was used. At a pH 3–3.5 rapid decomposition occurred with noticeable fiber damage.

Text. Research J. July 1949

Trends in Fabric Processing

Trends in fabric processing. F. Tripp. *Textile Bull.* **75**, 63–5 (Feb. 1949).

A description of the various systems of continuous scouring and bleaching. The chemical solutions used in the different methods are analyzed. All of the chemicals used in scouring and bleaching are based on the weight of fabric being processed and the speed of the cloth through the system. Only certain types of fabric, such as rayon and loosely woven cotton, can be scoured and bleached simultaneously in the same bath. A. L. Landau

Text. Research J. July 1949

Dyeing and Finishing

Changing aspects in dyeing and finishing. L. S. Thompson. *Am. Dyestuff Reptr.* **38**, P276–80 (Mar. 21, 1949).

See the "Current Development in Dyeing and Finishing" by L. S. Thompson, *Am. Dyestuff Reptr.* **38**, P6–8, P32, January 10, 1949.

Text. Research J. July 1949 C. A. A.

Naphthol Dyes

Naphthol dyeing and printing. R. H. Nuttall. *Am. Dyestuff Reptr.* **38**, P232–3 (Mar. 7, 1949).

Recipes and procedures are given for the use of naphthol dyes in package dyeing, raw stock dyeing, and hosiery dyeing. The two great evils in naphthol dyeing—crocking and bleeding—can be improved a great deal by using a cation-active, high-molecular organic product. The use of naphthol dyes in printing is also discussed. C. A. A.

Text. Research J. July 1949

Dyestuff Industry

Some present thoughts on the dyestuff industry. C. J. T. Cronshaw. *J. Soc. Dyers and Colourists* **65**, 52–5 (Feb. 1949).

A discussion of the very slow return to normal of the British textile industry. However, the industry is not static. In the past, new fibers have come to its use and skill, such as viscose, then cellulose acetate, and finally nylon. In the future, there will be Ardil and Terylene, Orlon and Vinyon. These newcomers in the textile field may find a place as individual fibers as well as in manifold combinations with other fibers. These new fibers present many problems to the dyestuff industry. C. Amick

Text. Research J. July 1949

FIBERS: YARNS: FABRICS: MECHANICAL PROCESSES

★

Properties of Orlon Fiber

Properties of Orlon fiber. Anon. *Textile Age* **13**, 20, 22, 24, 28, 32 (Jan. 1949).

A report of the properties and uses of Orlon, the new du Pont fiber. The fiber is compared with other synthetic fibers and cotton for strength, tenacity, and resistance to abrasion, flex, and exposure. A. L. Landau

Text. Research J. July 1949

Staple Rayon

Spun-dyed "Fibro." S. Potts. *Textile Weekly* **43**, 252, 254–6 (Feb. 4, 1949).

Particular reference is made to the blending of "Fibro" with cotton, wool, flax, etc., and to the interblending of the various colors with one another. Technical guidance in this matter of blending is developed to attain color solidity and an excellent range of color hues. There is illustrated a color-blending circle showing all the standard spun-dyed colors obtainable (with blending instructions). It is stated that this color-blending circle is useful in producing effect yarns by the exploitation of colors which tend to resist each other and retain their individuality. L. A. Fiori

Text. Research J. July 1949

Cotton-Waste Fabrics

A wealth of fabrics from cotton waste. Anon. *Platts Bull.* **6**, 109–11 (Nov.–Dec. 1948).

A brief outline—meant to serve only as a general guide—of the types of opening and cleaning machines recommended for soft, cotton wastes.

Text. Research J. July 1949 L. A. Fiori

Faults in Cotton Yarn

Common faults in cotton yarn. N. H. Pomfret. *Can. Text. J.* **66**, 42–3 (Feb. 4, 1949).

Imperfections, such as slubs, crackers, wiry yarn, etc., and preventive measures are discussed briefly.

Text. Research J. July 1949 L. A. Fiori

Monocord

Monocord joins family of textile yarn forms. Anon. *Textile World* **99**, 125, 216, 218 (Jan. 1949).

A new physical-structure thread of nylon has been introduced consisting of a continuous multifilament strand with the filaments cemented or welded together. The thread will not ravel and is said to have exceptional strength. A. L. Landau

Text. Research J. July 1949

Card Settings

Card settings. Anon. *Platts Bull.* **6**, 119–20 (Nov.–Dec. 1948).

A short description of two important card settings—the front plate and grinding motion. L. A. Fiori

Text. Research J. July 1949

High Drafting

High drafting. A. A. Hayes. *Textile Weekly* **43**, 270, 272, 274 (Feb. 4, 1949); **43**, 306, 308, 310 (Feb. 11, 1949).

A comprehensive review of the virtues of the Casablanca system of high drafting. Many illustrations and comparative examples of conventional *vs.* high-drafting systems are given. L. A. Fiori

Text. Research J. July 1949

Spinning

Pneumafil. Anon. *Platts Bull.* **6**, 102–3 (Nov.–Dec. 1948).

A short discussion of the advantages accruing from the use of a pneumafil system for the collection of broken ends on spinning frames.

Text. Research J. July 1949 L. A. Fiori

Fibre control in worsted spinning. W. Hodgson. *Text. Mercury and Argus* **120**, 179, 181, 183 (Feb. 4, 1949).

Outlined briefly are suggestions for worsted spinning manufacture leading to possible elimination of processes and improvement of quality. It is stated that the greatest need is for a high-draft spinning frame which would eliminate at least one roving operation and effect a 45% saving in labor and appreciable improvement in yarn quality.

Text. Research J. July 1949 L. A. Fiori

Thread trap for worsted yarn ring-spinning machines. B. Melin. *Tids. Textiltek.* **6**, 139–41 (1948) (through *Chem. Abstr.* **43**, 845*f* (Jan. 25, 1949)).

A new exhaust arrangement invented by the author for worsted yarn ring-spinning is described.

Text. Research J. July 1949

Weaving

Practical weave-room inspection methods. H. E. Wenrich. *Rayon and Synthetic Texts.* **30**, 51–3 (Feb. 1949).

Well-known and also ingenious procedures for detecting cloth imperfections are outlined. These methods are particularly adaptable to special conditions, such as high-pickage cloth, tricky weaves, different types of shedding motions and looms, etc. L. A. Fiori

Text. Research J. July 1949

Carpet Manufacturing

Modern trends in carpet yarn manufacturing. S. B. Hyde. *Whitin Review* **15**, 10–18 (Nov. 1948).

Modern trends in woolen carding, ring spinning, trap twisting, and dressing are described in general terms and with specific emphasis on carpet manufacturing. L. A. Fiori

Text. Research J. July 1949

MISCELLANEOUS

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Asbestos Laminates

Asbestos-base laminated plastic. E. G. Hancock. *Inst. Plastics Ind., Trans.* 77–88 (Jan. 1947) (through *Chem. Abstr.* **43**, 434*g* (Jan. 10, 1949)).

Physical and chemical properties are given for asbestos fabric laminates.

Text. Research J. July 1949

Hydrosulfite

Who was the discoverer of Hydrosulfite NF? R. Haller. (Translated by P. J. Wood.) *Am. Dyestuff Reptr.* **38**, 105–6 (Feb. 7, 1949). Reprinted from *Textile-Rundschau.*

On the basis of a study of the literature, the unbiased judge can come to no other conclusion than that Camille Kurz was the discoverer of hydrosulfite-formaldehyde and that the prior claim of Russina remains problematical. C.A.A.

Text. Research J. July 1949

Knitting Needles

Knitting needle design in relation to high-speed knitting. R. Peel. *J. Text. Inst.* **39**, P599–608 (Dec. 1948).

A well-illustrated and detailed account of knitting needle design, relative advantages and defects.

Text. Research J. July 1949 L. A. Fiori

Loom Let-off Motion

The "Richmond" let-off motion. Anon. *Textile Weekly* **43**, 276, 278 (Feb. 4, 1949).

In principle, this motion discards the heavy weights at the back of the loom used for applying tension to the warp and applies compression-style springs to produce and regulate a standard rate of tension on the yarn during weaving and at all warp diameters. Illustrated.

Text. Research J. July 1949 L. A. Fiori

Protection of Wool Against Mites

Evolution of processes for the protection of wool against mites. H. Ris and J. R. Geigy. *Teintex* **13**, 353–8 (1948) (through *Chem. Abstr.* **43**, 812*f* (Jan. 25, 1949)).

A review.

Text. Research J. July 1949

A.A.T.C.C.

Reports of research committees presented at general research committee meeting. *Am. Dyestuff Reptr.* **37**, P873–7 (Dec. 27, 1948).

Reports of the various committees on the progress made in research on wool detergency, flammability, light, dimensional changes, perspiration, and insect pests as they affect textiles. C.A.A.

Text. Research J. July 1949

President's address. H. F. Herrmann. *Am. Dyestuff Reptr.* **37**, P863, 877 (Dec. 27, 1948).

The president of the A.A.T.C.C. reviews the more notable developments of the organization during the past two years. The membership has grown from 5,000 to nearly 6,000, and the number of sections has increased from 8 to 11. C.A.A.

Text. Research J. July 1949

A.A.T.C.C. contributions to industry. H. F. Herrmann. *Am. Dyestuff Reptr.* **37**, P861, 877–8 (Dec. 27, 1948).

This paper by the president of the A.A.T.C.C. consists of a brief review of some of the work of the organization. C.A.A.

Text. Research J. July 1949

The importance of cooperative research. J. R. Bonnar. *Am. Dyestuff Reptr.* **37**, P862, 877 (Dec. 27, 1948).

This paper by the Chairman of the Executive Committee on Research and the Chairman of the General Research Committee of the A.A.T.C.C. gives a brief review of the work of these committees. C.A.A.

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